

A mining perspective on the potential of renewable electricity sources for operations in South Africa

by

Roman Günter Votteler

Dissertation presented for the degree of Doctor of Philosophy in the Faculty of Economic and Management Sciences at Stellenbosch University.



Supervisor: Professor Alan Colin Brent

Faculty of Economic and Management Sciences

December 2016

Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated); that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights; and that I have not previously, in its entirety or in part, submitted it for obtaining any qualification.

December 2016

Signature: R. Votteler

Date: 20.06.2016

Abstract

The economic situation in South Africa has in recent years presented considerable challenges for mining corporations to stay globally competitive. One of the challenges has been the increase in average electricity costs, which contributed especially to large corporates experiencing a rise from 7% to 20% in total operational expenses since 2007. This was brought about by the escalation of cost of the current electricity sources, namely diesel generators and grid connections to the state-owned electricity provider Eskom. Forecasts for the next decade indicate that this trend will continue at similar rates. It is also the case that recurring blackouts or load shedding have decreased the reliability of Eskom.

The technological and economic progress of renewable electricity sources in recent years has increased their attractiveness in comparison to the current sources. The use of renewable sources is, thus, a potential opportunity for mining corporations to reduce long-term electricity costs, diversify energy supply, become less dependent on fuel price volatility, decrease greenhouse gas emissions and show green leadership. However, with only one pilot hybrid diesel generator and solar photovoltaic project being realised in South Africa so far, the progress on the renewables front has only recently made it worthwhile for mining corporations to consider renewable sources.

The purpose of this research was, therefore, to investigate a possible fit regarding how renewable electricity sources can perform within South African mining operations with their specific characteristics. Consequently, to maximise the contribution to this field, it was important to include in the study, the perspective of mines on evaluating possible electricity sources.

The research process consisted of three phases. The first phase comprised a literature review, to investigate the influences on the possible use of renewables for mining operations in South Africa. During the second phase, a literature review was conducted to identify the best approach for the analysis of electricity sources, combining the external environment and an evaluation of internal processes of mining corporations. The multi-criteria decision analysis approach was selected. This was followed by an investigation of the different multi-criteria decision analysis methods. The multi-attribute value theory method was identified as the most suitable to be used, with specific adaptations for this study. Previous adaptations to similar cases in energy planning were analysed. The third phase involved conducting semi-structured interviews to reveal the internal evaluation

criteria used by mining corporations to evaluate electricity sources. Based on interviews with four mining corporations and five energy companies, the model was created and implemented.

The results of the study may contribute to the field of multi-criteria decision analysis and energy planning of mining corporations in that new insights were gained regarding the implementation of a multi-criteria decision analysis method to a corporate, especially mining, environment in energy planning. The outcome showed that the more profit-oriented nature and special characteristics of mines had an impact on the selection of evaluation criteria. Previous multi-criteria decision analysis approaches were conducted for governmental or general purposes.

The main results of the study contribute towards the performance of renewables for mining operations in South Africa. The analysis identified the current sources of diesel generators and grid-connection to Eskom in hybrid versions with either solar photovoltaic, on-shore wind or geothermal power, as the most attractive renewable options. The business model of self-generation was selected as most promising. To focus on technologies and reduce variables, the project had to be funded through of own-investment.

The implementation and analysis of the multi-attribute value theory method showed that the hybrid versions with solar photovoltaic and on-shore wind always performed favourably in comparison with diesel generators or Eskom grid-connection alone. The advantage over diesel generators is significantly higher than over Eskom grid-connection. In combining the macro-economic influences with the multi-attribute value theory results of this study, hybrid solar versions are identified as having the greatest potential. Hybrid wind solutions were placed second in the evaluation, as favourable wind conditions occur only in coastal regions where there are fewer mining activities. Geothermal hybrid versions were selected as the least favourable owing to a low service infrastructure and high initial investment costs.

Acknowledgements

I have many people to thank for contributing in various ways to the completion of this dissertation. I am especially grateful to:

- My promoter, Professor Alan Brent, for keeping me on track, valuable input, expertise, professionalism and network of experts.
- My mother Monika, without her support, this study wouldn't have been possible. She encouraged me when I needed it the most. Since I've never seen a person that is always positive as she is towards life, she gave me the strength and power to go through the ups and downs during my research.
- My father Günter, who always supported me with great advice from Germany. I was gifted to learn from his character to be trustworthy, reliable and diligent, which helped me a lot in this achievement.
- My stepfather Jo, for his unconditional support and helpful advice. I am very grateful that he became part of my life and family. He has taught me to think outside of the box and how to see the positive aspects of life. His life experience helped me several times during my research process.
- My aunt Ingrid, who always found motivating words whenever it was needed.
- My love Chloe, for supporting me throughout the whole research process. Her motivating words gave me a lot of strength during challenging stages. I'm really happy that she is part of my life!
- The Centre for Renewable and Sustainable Energy Studies of Stellenbosch University for providing me with financial support to collect my data.
- Cronimet Power Solutions for all their valuable input and expertise, regarding the realization of hybrid power solutions for mining operations.
- All experts who shared their knowledge and contributed to the success of my research.

Table of Contents

Chapter 1 Introduction	1
1.1 Background and motivation	1
1.2 Evolution of the research focus	2
1.3 Research objectives.....	5
1.4 Research purpose.....	6
1.4.1 Justification of the research.....	7
1.4.2 Original research contribution of the dissertation.....	8
1.5 Research methodology.....	9
1.5.1 Secondary research	10
1.5.2 Chapter 2	11
1.5.3 Chapter 3	11
1.5.4 Chapter 4	13
1.5.5 Chapter 5	13
1.6 Research overview and structure	15
Chapter 2 A literature review on the potential of renewable electricity sources for mining operations in South Africa	18
2.1 Introduction	18
2.2 Mining operations	19
2.2.1 South African Landscape	19
2.2.2 Electricity pattern of mining operations.....	22
2.2.3 The demand profile	25
2.2.4 Hybrid concepts	27
2.2.5 A global overview of existing projects.....	30
2.3 Attractiveness of electricity sources	34
2.4 Business models.....	42
2.5 Corporate development	45
2.6 Environmental factors	47
2.7 Core information for the following research	48
2.8 Conclusion	49
Chapter 3 Selection and assessment of possible research approaches: A review	51
3.1 Introduction	51
3.2 Method selection.....	52
3.2.1 Requirements of the method	52
3.2.2 Possible methods.....	53
3.2.3 Selection of strategic method	57
3.3 MCDA method selection	58

3.3.1	Requirements of the MCDA method.....	58
3.3.2	Possible MCDA methods	59
3.4	Existing applications to similar cases	62
3.4.1	Previous MCDA approaches to energy planning	62
3.4.2	Evaluation criteria in previous MCDA approaches.....	69
3.4.3	Impact on the MCDA approach for mining corporations	71
3.5	Conclusion	71
Chapter 4	Creation process of the MAVT model.....	73
4.1	Introduction	73
4.1.1	Profile of mining corporations.....	74
4.1.2	Step 1: Problem definition	75
4.1.3	Step 2: Determine evaluation criteria.....	77
4.1.4	Step 3: Develop a measurement scale for each criterion.....	79
4.1.5	Step 4: Define value functions and relative importance weights	79
4.1.6	Step 5: Determine results.....	81
4.2	Conclusion	81
Chapter 5	A mining perspective on the potential of renewable electricity sources for operations in South Africa: A multi-criteria decision assessment.....	83
5.1	Introduction	83
5.2	The MAVT for mining corporations to evaluate electricity sources	84
5.2.1	The decision criteria	84
5.2.2	Selected electricity sources	86
5.2.3	Key values used for calculations	87
5.2.4	The criteria and value functions.....	88
5.3	Results.....	94
5.3.1	The overall ranking of electricity sources.....	94
5.3.2	The individual performance of electricity sources	95
5.3.3	Discussion of results	100
5.4	Sensitivity analysis	102
5.4.1	Lifespan of the project.....	102
5.4.2	Eskom tariff and diesel price forecast analysis	104
5.4.3	Implications of a CO ₂ tax.....	105
5.5	Conclusion	107
Chapter 6	Summary of findings and Conclusion.....	108
6.1	Contribution.....	108
6.2	Summary of findings: Phase one.....	109
6.2.1	A possible fit of renewable sources to mining operations	109

6.2.2	Current attractiveness of different renewable sources	110
6.2.3	Potential of different business models	111
6.2.4	Additional influences on the market.....	111
6.3	Summary of findings: Phase two	112
6.3.1	The selection of the most suitable research approach.....	112
6.3.2	Previous adaptations to similar cases	112
6.4	Summary of findings: Phase three	113
6.4.1	Evaluation criteria for mining corporations.....	113
6.4.2	Adaptation of the MCDA method.....	113
6.4.3	Analysis and comparison of current to renewable electricity sources for mining operations in South Africa	114
6.4.4	Sensitivity analysis	114
6.5	Limitations of the study and opportunities for future research	115
6.6	Conclusion	117
	References	118
	Addendum A: Interview Protocol	141
	Addendum B: Questionnaire for mines to identify evaluation criteria.....	142
	Addendum C: Semi-structured questionnaire for electricity sources data	148
	Addendum D: Post-it-sessions.....	159
	Addendum E: Mining interviews to identify value function and importance weight.....	160
	Addendum F: Example of data collection.....	162
	Addendum G: Price scenario of carbon tax on Eskom tariff	163
	Addendum H: Definition of importance weights	164
	Addendum I: Comparison of electricity sources according to criteria	165

List of abbreviations

AHP	analytical hierarchy process
BRIC	Brazil; Russia; India; China
CO ₂	carbon dioxide
CPV	concentrated photovoltaic
CSP	concentrating solar power
DEA	Department of Environmental Affairs
DOE	Department of Energy
DSM	Demand Side Management
DTI	Department of Trade and Industry
EDC	Energy Development Corporation
EIUG	Energy Intensive User Group of Southern Africa
Eskom	South Africa's state-owned electricity provider
GEA	Geothermal Energy Association
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
Hz	Hertz
IEA	International Energy Agency
IMF	International Monetary Fund
IPP	independent power producer
IRENA	International Renewable Energy Agency
IRP	integrated resource plan
kV	kilovolt
kVA	kilovolt-ampere
kW	kilowatt
kW/m ²	kilowatt per square metre
kWh	kilowatt-hour
kWh/m ²	kilowatt-hour per square metre
LCOE	levelised cost of electricity
m	metre
MACBETH	measuring attractiveness by a categorical based evaluation technique method
MAVT	multi-attribute value theory
MCDA	multi-criteria decision analysis
MVA	megavolt ampere
MW	megawatt

NERSA	National Energy Regulator of South Africa
NREL	National Renewable Energy Laboratory
O&M	operating and maintenance
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PESTLE	political, economic, social, technological, legal, environmental
PPA	power purchase agreement
REBID	renewable energy bids
REFIT	Renewable Energy Feed-In Tariff Program
REIPPP	renewable energy independent power producer procurement
ROW	rest of the world
SAPVIA	South African Photovoltaic Industry Association
SAWEA	South African Wind Energy Association
Solar PV	solar photovoltaic
W/m ²	watt per square metre
WASA	Wind Atlas for South Africa

List of Figures

FIGURE 1.1: EVOLUTION OF THE RESEARCH FOCUS	3
FIGURE 1.2: RESEARCH OBJECTIVES	5
FIGURE 1.3: RESEARCH PURPOSE OVERVIEW	6
FIGURE 1.4: RESEARCH PROTOCOL AND METHODOLOGY	10
FIGURE 1.5: RESEARCH OVERVIEW.....	17
FIGURE 2.1: RESEARCH OBJECTIVES OF CHAPTER 2	18
FIGURE 2.2: AFRICAN COMPARISON OF SECURITY OF ELECTRICITY SUPPLY	19
FIGURE 2.3: AFRICAN COMPARISON OF ELECTRICITY TARIFFS FOR MINES FIRMS	20
FIGURE 2.4: PREDICTION OF MINING POWER DEMAND UNTIL 2020	21
FIGURE 2.5: CUMULATIVE POWER REQUIREMENTS AT STAGES OF BENEFICIATION	23
FIGURE 2.6: ELECTRICITY DEMAND BY PROCESSING STAGE.....	24
FIGURE 2.7: UNDERGROUND AND SURFACE MINING ELECTRICITY DEMAND.....	24
FIGURE 2.8: ELECTRICITY DEMAND PROFILE OF AN UNDERGROUND GOLD MINE.....	25
FIGURE 2.9: ELECTRICITY DEMAND PROFILE OF AN UNDERGROUND GOLD MINE.....	26
FIGURE 2.10: ELECTRICITY DEMAND PROFILE OF AN UNDERGROUND COAL MINE	26
FIGURE 2.11: PRINCIPLE OF A HYBRID SYSTEM	29
FIGURE 2.12: ELECTRICITY DEMAND PROFILE OF A SURFACE CHROMIUM ORE MINE	30
FIGURE 2.13: MINING MAP SOUTH AFRICA	36
FIGURE 2.14: ESKOM POWER STATIONS AND GRID	37
FIGURE 2.15: SOLAR RESOURCE QUALITY ACROSS SOUTH AFRICA.....	38
FIGURE 2.16: WIND RESOURCE QUALITY IN SOUTH AFRICA.....	39
FIGURE 2.17: GEOLOGICAL MAP OF SOUTH AFRICA	39
FIGURE 2.18: NET PRIMARY PRODUCTIVITY OF THE LAND.....	40
FIGURE 2.19: HYDRO POWER POTENTIAL	41
FIGURE 3.1: RESEARCH OBJECTIVES	51
FIGURE 4.1: THE MULTI-ATTRIBUTE VALUE THEORY PROCESS	73
FIGURE 4.2: EXAMPLE OF O&M COST VALUE FUNCTION	80
FIGURE 5.1: RESEARCH OBJECTIVES	84
FIGURE 5.2: OVERALL RANKING OF ELECTRICITY SOURCES	94
FIGURE 5.3: DIESEL – HYBRID DIESEL/SOLAR PV	95
FIGURE 5.4: DIESEL – HYBRID DIESEL/ON-SHORE WIND	96
FIGURE 5.5: DIESEL – HYBRID DIESEL/GEOTHERMAL	97
FIGURE 5.6: ESKOM – HYBRID ESKOM/SOLAR PV	98
FIGURE 5.7: ESKOM – HYBRID ESKOM/WIND.....	99

<i>FIGURE 5.8: ESKOM – HYBRID ESKOM/GEOTHERMAL</i>	100
<i>FIGURE 5.9: EFFECT OF PROJECT LIFESPAN ON LEVELISED COST OF ELECTRICITY</i>	103
<i>FIGURE 5.10: EFFECT OF PROJECT LIFESPAN ON NET PRESENT VALUE</i>	104
<i>FIGURE 5.11: EFFECT OF DIESEL PRICE AND ESKOM TARIFF PREDICTION ON LEVELISED ELECTRICITY COSTS</i>	105
<i>FIGURE 5.12: EFFECT OF DIESEL PRICE AND ESKOM TARIFF PREDICTION ON NET PRESENT VALUE</i>	105
<i>FIGURE 5.13: EFFECT OF CO₂ TAX ON LEVELISED ELECTRICITY COSTS</i>	106
<i>FIGURE 5.14: EFFECT OF CO₂ TAX ON NET PRESENT VALUE</i>	106

List of Tables

<i>TABLE 2.1: GLOBAL OPERATING RENEWABLE ENERGY PROJECTS AT MINING LOCATIONS</i>	32
<i>TABLE 2.2: ELECTRICITY-GENERATING TECHNOLOGIES FOR SOUTH AFRICAN MINES</i>	34
<i>TABLE 2.3: GOVERNMENTAL AND REGULATORY STRUCTURE FOR RENEWABLE ENERGY IN SOUTH AFRICA</i>	42
<i>TABLE 2.4: ENERGY EFFICIENCY PROGRAMMES OF EIUG MEMBERS</i>	46
<i>TABLE 2.5: OVERVIEW OF RESULTS OF CHAPTER 2</i>	49
<i>TABLE 3.1: POSSIBLE STRATEGIC METHODS</i>	53
<i>TABLE 3.2: SELECTION PROCESS OF MCDA METHOD</i>	59
<i>TABLE 3.3: REVIEW OF MCDA APPROACHES IN ENERGY PLANNING</i>	65
<i>TABLE 3.4: REVIEW OF CRITERIA USED IN ENERGY PLANNING MCDA APPROACHES</i>	70
<i>TABLE 4.1: CHARACTERISTICS OF MINING CORPORATIONS INTERVIEWED</i>	74
<i>TABLE 5.1: EVALUATION CRITERIA OF MINING CORPORATIONS</i>	85
<i>TABLE 5.2: ELECTRICITY SOURCES</i>	87
<i>TABLE 5.3: BASIC VALUES OF ELECTRICITY SOURCES</i>	87
<i>TABLE 5.4: SPECIFIC VALUES OF ELECTRICITY SOURCES</i>	88
<i>TABLE 5.5: SUMMARY OF FINAL CRITERIA DATA</i>	90
<i>TABLE 5.6: QUALITATIVE SCALES</i>	93
<i>TABLE 5.7: PERFORMANCE OVERVIEW OF CURRENT AND HYBRID RENEWABLE ELECTRICITY SOURCE</i>	101

Chapter 1 Introduction

1.1 Background and motivation

This section provides a brief overview of the background of and motivation for the study. To assure internal consistencies of the various sections cross-referencing is done where necessary.

The cost of electricity for mining corporations in South Africa has substantially increased in the past few years. Currently, electricity is supplied mainly by Eskom¹ and, especially in remote locations, by on-site diesel generators (Boyse et al., 2014). Electricity price increases resulting from diesel price hikes and Eskom tariffs, have escalated the total operational expenditure of the largest mining corporations on electricity from 7% to 20% in the past seven years (see sections 2.2; 2.6) (EIUG, 2015). The reliability of electricity supplied by Eskom has also decreased drastically (Govender, 2008; Odendaal, 2015) and it is predicted that the prices will increase annually by at least 13% till 2018 (Numbi et al., 2014; Eskom, 2015c). The diesel price is also predicted to increase annually by at least 7% in South Africa during the next decade (see section 2.3) (OPEC, 2014; South African Reserve Bank, 2015). In addition, the South African government plans to launch a carbon emission tax, which could increase the electricity price of current electricity sources (see section 2.4) (Alton et al., 2014).

The past and predicted future electricity price escalations in South Africa could damage the global competitiveness of mining corporations (Creamer, 2012). Moreover, the uncertainty around reliable electricity supply and carbon emissions management hinders possible future development (see sections 2.2; 2.3; 2.6) (Kohler, 2014).

Given this scenario, the usage of renewable sources of energy has the potential to be an opportunity for mining corporations to reduce long-term electricity costs, diversify energy supply, be less dependent on fuel price volatility, decrease greenhouse gas emissions, and show green leadership (Nicolas, 2014). Thus, the combination of technological progress regarding renewable sources and factors in the external environment, like increasing fossil fuel prices and pressure to become greener, increases the attractiveness of renewable sources for mining corporations (Roehrl and Riahi, 2000; Crespo, 2015a).

¹ South Africa's state-owned electricity provider (Eskom, 2015e)

Based on this development, the usage of renewables for mining operations globally only started to increase meaningfully in 2012, including the so far first and only pilot 1 MW project in South Africa (see section 2.3.2). To assist mining corporations in evaluating this new developing opportunity, more research should be conducted about renewable energy technologies and a possible fit to their specific needs, depending on their own perspective (see sections 2.2 - 2.4; 2.6) (Crespo, 2015b). Moreover, mining corporations are relatively new customers for renewable energy companies, as present target customers are mostly governmental organisations, electricity suppliers and private residential bodies (Day, 2014).

Research can contribute to the optimisation of the evaluation process for mining corporations to understand if and how renewable energy technologies could fit their needs and for energy companies to learn how to approach these potential new customers (see section 1.4.1) (Steinhaeuser et al., 2012). One of the outcomes of several renewables and mining summits² worldwide is the fact that mining corporations have to be better educated about the concept of renewable sources in the context of their unique operational demands (Judd, 2014b).

1.2 Evolution of the research focus

The evolution of the research focus of this study was a lengthy process – and with the end in mind the following sections help to understand the process and steps to reveal the maximum potential to create knowledge. The foundational thought behind this study was to increase transparency and knowledge regarding the new evolving opportunity for large-scale electricity users in South Africa to use renewable electricity sources to counteract the current negative developments surrounding current sources. With each attempt by the researcher to approach a possible solution to add value to this foundational thought, more information was collected and experience was gained, which eventually made it possible to find the solution presented in this study. A timeline of the main steps in the evolution of the research focus is presented in Figure 1.1.

² Summits of mining corporations and renewable energy companies took place from 2013, with the aim of developing and discussing the use of renewables for mining operations (Energy and Mines, 2015).

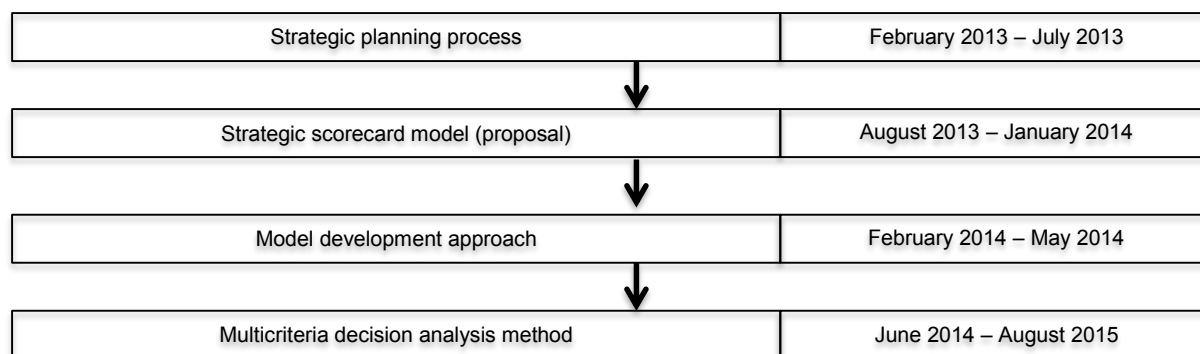


Figure 1.1: Evolution of the research focus

Throughout the whole research process contact with consulting firms, energy companies, mining corporations and academic experts provided enormous assistance to find the best possible approach to investigate the opportunity of renewable sources for large-scale electricity users. The following section introduces each attempt briefly and provides the main motive to move forward:

- A strategic planning process – This was the first attempt to increase transparency for independent renewable energy companies on how to enter the South African market and specifically, how to approach mining corporations. Firstly, the study would have conducted an investigation to identify possible on-site renewable electricity sources and compare the analysis to currently used on-site diesel generators. Secondly, a market analysis would have been conducted to evaluate mining corporations, which are more or less attractive targets for renewable energy projects. Lastly, possible strategies to approach and realise projects with the identified mining corporations would have been investigated.

There was one main reason why this approach was only partially investigated. It became clear that it does not make sense to undertake research from the perspective of energy corporations. After numerous inputs from experts and a literature investigation, it was evident that more value would be added if the issue was addressed from the perspective of large-scale electricity users, as they are the ones that are not familiar with the concept of using renewables.

- A strategic scorecard model – This was the second attempt to create transparency for large-scale electricity users in South Africa. Firstly, an investigation was conducted to create more knowledge about markets, specifically, and diesel generators and

renewable on-site sources. Secondly, a scorecard with the main elements of financial, strategic, operational and external factors would have been created and implemented. Here, interviews were conducted with five different energy companies.

The model was created for the use of large-scale electricity users to understand what it would entail to achieve the target of using on-site renewable electricity sources. However, a problem occurred where the scorecard was only created with the input of energy companies. The tool indicates the criteria, which have to be achieved in order to successfully implement renewable energy technologies. The specific characteristics of large-scale electricity users were not considered, which made this approach less effective. Furthermore, the tool did not analyse and evaluate a possible fit of renewables for mining operations based on their own perspective. The result would have been an indication for mining operations to see what has to be achieved in order to successfully implement renewables. Consequently, it would not be possible to evaluate a possible fit.

- The multi-criteria decision analysis (MCDA) – This method was finally selected as the most suitable for the purpose of this study. The selection of the method entailed two steps. Firstly, developing a new model from the perspective of mines in order to incorporate their unique characteristics. During the literature review, several studies analysing electricity sources especially from the perspective of governmental bodies were found. Thereafter, through further research into similar strategic approaches, the MCDA was selected.

The method enabled the analysis of the different electricity options from the perspective of mines while at the same time benefiting from previous applications to similar cases. The investigation of the previous approaches was redone to fit the new requirements. Through further inputs from experts, the final research focus of comparing the currently used sources of Eskom grid-connection and diesel generators, to hybrid versions with on-site renewable sources was established. Furthermore, the focus of this study was directed at mining corporations owing to their comparable characteristics and large presence in South Africa.

1.3 Research objectives

The main purpose of this study was investigate a possible fit and to increase transparency regarding how renewable electricity sources can perform with respect to the specific electricity usage characteristics of mining operations in South Africa. As can be seen in Figure 1.2, the research process was sub-divided into three phases. The first phase investigated the influences on the market with respect to renewables for mining operations in South Africa. The second phase investigated and assessed the most suitable research approach. Lastly, the identified research approach was implemented, incorporating the knowledge about the external and internal environment.



Figure 1.2: Research objectives

1.4 Research purpose

This section explains why this research was conducted. Figure 1.3 provides the logical build-up of reasoning. The first part provides a summary of the research foundation, which was set out in the introduction of this chapter. The second part provides the justifications for conducting this research, which are discussed in section 1.4.1. The last part discusses the study's contribution to the theoretical field of multi-criteria analysis and to the practical energy planning at mining corporations in South Africa, which are examined in section 1.4.2.

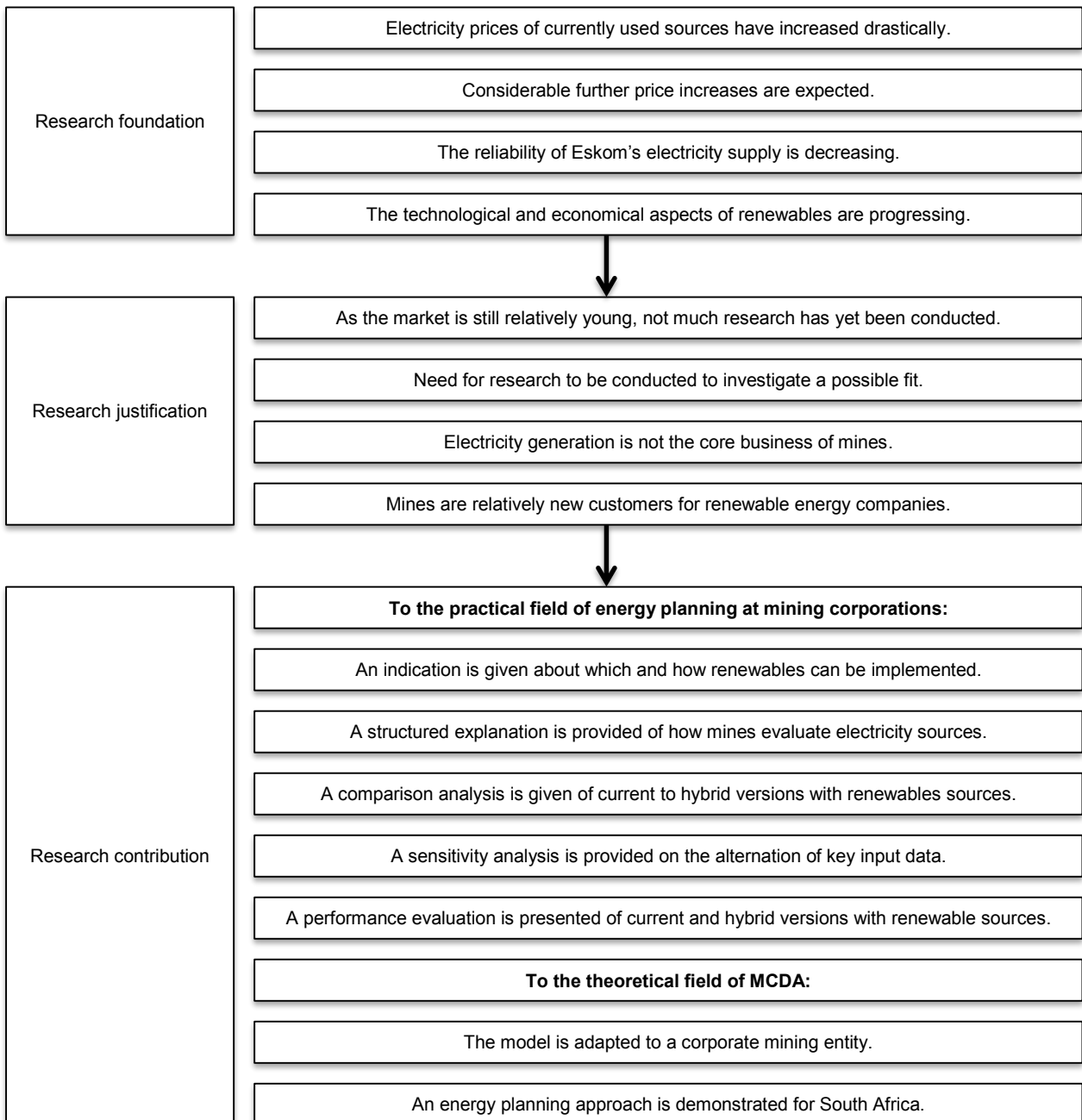


Figure 1.3: Research purpose overview

1.4.1 Justification of the research

The key points to justify the research listed in the middle section of Figure 1.3 are briefly discussed, which are based on opinions of experts and the literature review in chapter 2. These include:

- Mining corporations using renewable sources to contribute to their electricity consumption only started to increase globally in 2012 (see Table 2.1). South Africa, with its abundance of mining activity, has only implemented one solar PV pilot project. Consequently, not much research, from the perspectives of mines, has been conducted to generate more clarity about the potential of this opportunity. Greater transparency can contribute to creating a better understanding and, thus, facilitate progress (Steinhaeuser et al., 2012; Judd, 2014b).
- Academic research on the specific needs of mines also contributes to an improved understanding. The existing research originates from the business environment and may have adopted a more subjective approach from the viewpoint of the company and its business interests. Since this study is academic in nature, the various electricity sources were analysed uniformly. In addition, no research could be found based on the perspective of mines, which analyses aspects of electricity sources from a broader point of view. Previous work covering certain areas that also contribute to this research were from Boyse et al. (2014); Gets and Mhlanga (2013); Brodsky, Curnow, Fevre, Ghannam, Nasrollah and O'Brien (2013). This research aims to especially assist the management of mines to understand if, how and which renewable electricity sources could add value with regard to their specific needs.
- Electricity generation is not the core business of mining corporations; consequently, it is difficult for the mines' management to understand the implications of the new opportunity of renewables. As the implementation of renewables means a shift from currently operational to capital expenses, the management is likely to be sceptical, especially in the absence of enough understanding. Research based on the evaluation process of the mines themselves can contribute to a better understanding (Day, 2014; Wouter, 2014).
- Mining corporations are relatively new customers for renewable energy companies. The study can, therefore, contribute to more clarity for these renewable energy companies of the decision-making process for mining corporations. Information on the evaluation criteria and their relative importance can improve the communication and optimise the offers, if energy companies know more about their potential customers (Day, 2014; Grist, 2014).

1.4.2 Original research contribution of the dissertation

It is important to emphasise that the main focus of this research is the main objective as stated in Figure 1.2, that is, to investigate a possible fit regarding how renewables can perform with respect to the specific characteristics of mining operations in South Africa. It is also crucial to emphasize here that the results from this study cannot be generalized to all mining operations as characteristics might differ, rather it should provide guiding information to the opportunity of this market. Nevertheless, characteristics of different mining corporations are investigated to be as homogenous as possible (see section 2.2). The contribution to the theoretical field of MCDA is an additional, secondary outcome. The contributions of this study are listed in the last part of Figure 1.3 and are explained in the following points:

- The types of renewable electricity sources that have the highest potential to contribute to the electricity supply of mining operations in South Africa have been investigated. The main factors considered were the availability of the power source, the service and emergency infrastructure, the price structures, and the usage characteristics of mining operations (see sections 2.2-2.3). In addition, the most lucrative business model has been identified in accordance with the current legislative and regulatory framework (see section 2.4).
- A structured explanation of how mines evaluate electricity sources has been created in two steps. Firstly, an examination was conducted on how to best investigate the evaluation process. It was argued that the use of a research approach in the form of the MCDA method would be the best solution (see section 3.3). The results provided clear information on the evaluation criteria used, the relative importance and the preferences, with the different scores of each criterion (see sections 5.2).
- Based on the adapted and implemented MCDA method, a performance evaluation of the currently used electricity sources and hybrid versions with the identified renewable sources was conducted. The results, based on the evaluation process of the mining corporations, showed how each source performs, specifically the current source alone compared with the hybrid versions (see section 5.3.1).
- A comparative analysis of the currently used sources and the different hybrid versions was conducted, which was again based on the MCDA method. It is illustrated how the different sources performed in comparison to each other, based on the evaluation criteria. An overall ranking was produced and all sources were compared, based on their strengths and weaknesses (see section 5.3.2).

- A sensitivity analysis was conducted showing how the overall ranking and the performance on selected evaluation criteria were affected when uncertain input data were alternated. The data considered were criteria that were forecasted, namely Eskom tariffs, diesel prices and the impact of a potential CO₂ tax. In addition, the impact of alternating the lifespan was investigated (see section 5.4).
- The theoretical contribution to the body of knowledge of MCDA has two factors. Firstly, the research gave first insight into how corporate entities, especially mining corporations, conduct their energy planning. The differences in the criteria used to evaluate possible electricity sources were significant, as previous adaptations were done primarily from a governmental or general decision-maker perspective (see section 3.4). Secondly, the research introduced a MCDA adaptation in energy planning based on a South African context. Both contributions created a more solid foundation for future MCDA investigations in similar areas.

1.5 Research methodology

An overview of the research methodology of this study is illustrated in Figure 1.4. The first column on the left represents the different research phases of the chapters. Chapter one and six are not included as they represent the overview and summary of the study. The second column indicates the research approach for each phase. It is important to mention that the whole research process is interconnected and constant discussions with experts assured accuracy and valuable input (see Addendum A). Newly gained information during the research process had a possible influence on previous steps, which had to be reconsidered.

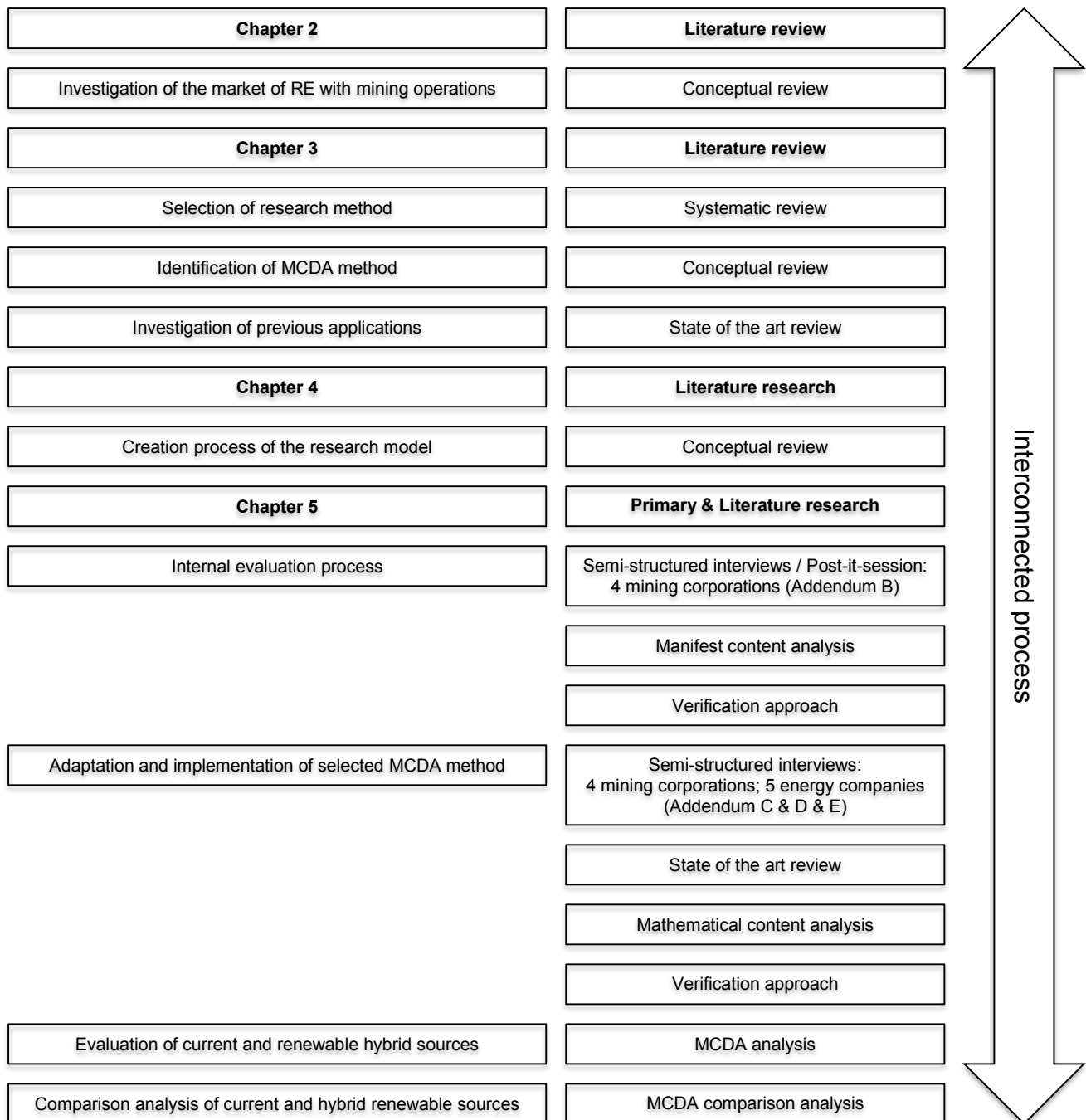


Figure 1.4: Research protocol and methodology

1.5.1 Secondary research

To conduct secondary research, data are used that were gathered and recorded by others prior to the current project. The advantages hereof are the assurance of readily available data and the relatively quick and inexpensive acquisition of such data. The disadvantages may be that the information is outdated, that there is a variation in the definition of terms, and that different units of measurement were used. The disadvantages can be reduced by cross-checking the data, which means comparing similar data (Zikmund and Babin, 2010).

Throughout the research process, the resources used for the literature review included books, internet sites, conference proceedings, journal articles, master's and doctoral dissertations as well as case studies.

Petticrew and Roberts (2006) identified six different types of literature reviews, namely: systematic review, narrative review, conceptual review, traditional review, critical review and state of the art review. The three types of reviews employed in this research include:

- Conceptual review: aims to synthesise areas of conceptual knowledge that can contribute to a better understanding of these issues. The objectives of these syntheses are to provide an overview of the literature in a given field, including the main ideas, models and debates (Petticrew and Roberts, 2006).
- Systematic review: a review that aims to comprehensively identify all relevant studies to answer a particular question, and assess the validity (or 'soundness') of each study and taking this into account when reaching conclusions.
- State of the art review: this term is sometimes used to refer to reviews designed to bring readers up to date on the most recent research on a specific subject. What constitutes 'recent' can vary, as can the methods of reviews. State of the art reviews tend to focus on technical subjects such as engineering.

1.5.2 Chapter 2

A conceptual review was conducted. The literature – conference and journal papers, theses and dissertations, and industry reports from 2008 onwards – was reviewed until the information was found to be repeated in new texts. This approach assisted in identifying key factors and their potential effect on the realisation of renewable electricity projects by mining corporations in South Africa. Based on the fact that the objectives are broad and a vast amount of information exists, this approach was deemed most suitable. Other approaches like a systematic review would be too detailed and extensive.

1.5.3 Chapter 3

The literature research approach in chapter 3 entailed the following three phases:

- The first phase was to select an appropriate research method. The review aims to identify relevant studies in order to answer a particular question, and to assess the

validity (or soundness) of each study, when reaching conclusions (Petticrew and Roberts, 2006). This was conducted on the basis of a systematic literature review. Firstly, the requirements of the method were listed and explained. Secondly, the three methods with the highest potential were investigated, namely multi-criteria decision analysis (Ishizaka and Nemery, 2013), balanced scorecard (Westermann and Sehl, 2006) and strategic planning (King and Cleland, 1987). The multi-criteria decision analysis was selected (see section 3.2). All steps focused on academic literature to gain the necessary information.

- The second phase identified the most suitable MCDA method, which was based on a conceptual review. Firstly, requirements of this research to identify the most suitable MCDA method were given and explained. By fulfilling the requirements it was possible to ensure that all the areas of the investigation were addressed. Secondly, the different MCDA 'schools of thought' were introduced and a possible use according to the requirements was discussed. The value measurement school of thought was selected (see section 3.3). The next step was to use the same requirements to analyse the possible contribution of each method. Three well-established and comprehensive methods were investigated, whereof one MCDA method was selected for the purpose of this research.
- The third research phase was to identify previous approaches of the selected research method in energy planning in similar cases. The researcher conducted a state-of-the-art review. Firstly, previous publications in the energy planning field were sourced and key characteristics contained therein tabulated. The aim was to investigate in which areas research had already been conducted and the areas where new adaptations had to be made for the purpose of this research. Secondly, an overview of the results generated in the publications identified was provided. The overview was of assistance in the interviews as basic background knowledge of applications in similar cases.

The aim was to provide a substantial overview of the selected research methods in energy planning that were implemented between 2001 and 2015. Therefore, 26 different papers were identified, 13 purely from a renewable energy perspective and 13 from a mixed conventional/renewable energy perspective.

1.5.4 Chapter 4

A conceptual review was conducted for the purpose of this chapter to illustrate and explain the creation process of the MCDA model. The literature review provided the reader with the necessary background information to follow the building up sequence of the model development. Literature frequently used was from Stewart and Belton (2002), Keeney (1996) and Boyse et al. (2014). The sequence described was conducted to adapt and implement the model in chapter 5.

1.5.5 Chapter 5

Semi-structured interview questionnaires were set up throughout the research process to collect the necessary information (see Addendum B and C). As no approach of the selected method for energy planning from a corporate perspective was found, a qualitative exploratory research technique was used to identify the evaluation criteria and input data. Firstly, the questionnaire would draw accurate information from respondents. Secondly, it would provide structure to the interview. Thirdly, it would provide standards from which facts, comments and attitudes could be written down. Lastly, it would facilitate data processing, as answers would be recorded in a common place on each questionnaire (Hague and Jackson, 1995).

The research approaches of chapter 5 entailed four phases. Three and four research steps were required for the first phase and the second phase respectively, as discussed below.

- The first phase was to investigate the internal evaluation process of mining corporations in South Africa, which entailed three research steps:
 - Firstly, semi-structured interviews were conducted with four different mining corporations with a total of 11 mining operations (see Addendum B). The respondents were firstly interviewed face-to-face to elicit information about the evaluation process. During the main part of the interview, a post-it session was used to generate all information in a structured manner (example can be seen in Addendum D).
 - Secondly, the collected data were analysed and sorted based on the procedures of content analysis. The coding was used to reduce the number of individual responses to a few general categories and themes of answers (Zikmund and

Babin, 2010). If two or more of the respondents mentioned a criterion, it was added to the study (see section 4.1.3.2).

- The third step, a verification approach was used throughout the whole phase explained above, i.e. the constructed table was sent back to the respondents via e-mail to obtain confirmation that it reflected their practices accurately. The verification approach was, in essence, a series of sequential rounds, interspersed by controlled feedback that sought to gain the most reliable consensus on the opinions of respondents.
- The second phase adapted and implemented the selected MCDA method to create the model, which consisted of four research steps:
 - The first step was to adapt the MCDA method to the requirements of this study and to feed the model with real-time data. Semi-structured interviews were conducted with nine companies. In the beginning five different energy companies participated to feed the model with real-time data (details of questionnaire in Addendum C). Thereafter, four mining corporations were involved in providing the necessary information to adapt the model (details of data collection in Addendum E and F).
 - Secondly, a state of the art review was conducted to compare the revealed real-time data with professional and reliable sources. The resources used were: IRENA; SARS; NREL; EIA and Eskom.
 - Thirdly, a mathematical analysis was conducted with the data from the mining corporations. For each criterion, the average of the four responses was taken (see section 4.1.5).
 - And lastly, a verification approach was used again during the research phase, to assure the average responses reflect the perspective of the participating mining corporations.
- The third phase was to evaluate the performance of current sources alone first, then in hybrid versions with the selected renewable sources. A matrix illustrating the scores of each criterion (Stewart and Belton, 2002) with and without the relative importance was created for each hybrid version with the corresponding current source alone. The purpose was to see how hybrid versions and current sources alone perform.

- The last phase involved conducting a comparison analysis by calculating the overall score (Stewart and Belton, 2002) of each electricity source option analysed in this study. After considering all criteria, the overall score indicated how the sources would be ranked from the perspective of the mining corporations.

1.6 Research overview and structure

This section provides an overview to illustrate to the reader how this research report is organised. Figure 1.5 illustrates the process. The original format of chapter 2 was an article for the *Journal of Energy in Southern Africa*. Chapter 3, 4 and 5 were extracted from the essence of a package of two articles, which were prepared for the *Journal of the Southern African Institute of Mining and Metallurgy*:

- Chapter 1 is an introduction to the study and provides background information to the topic being investigated, the evolution of the research focus, the research objectives, the nature of the topic, the methodology and the contribution and limitations of the study. The aim is to provide the reader with enough information to understand why the study is conducted, how the results were generated and the contribution the study makes to the research and knowledge gap.
- Chapter 2 represents the first research phase of the study. The influences on the market of renewables for mining operations in South Africa are investigated. The main topics studied are: the electricity usage patterns of mining operations; how renewable electricity sources could fit into their patterns; the renewable sources with the highest potential; the most lucrative business model; an overview of globally realised projects; as well as the status quo of electricity initiatives of mining corporations in South Africa.
- Chapter 3 assesses different research approaches and selects the most appropriate one for this study. The chapter entails three steps. Firstly, the best research approach to achieve the main research objective in Figure 1.2 was investigated. The MCDA approach was selected. Secondly, the multi-attribute value theory (MAVT) was selected as the best suited MCDA method. Lastly, previous MCDA approaches in the energy planning field were identified and analysed. The information and experience gained, assisted in the adaptation and implementation process of the following chapters.

- Chapter 4 illustrates and clarifies the adaptation and implementation process of the MCDA method selected in chapter 3. The literature information for each step of the model creation is explained, followed by a description of how it was conducted for the purpose of this study. The chapter represents the link between the previously generated information from the literature review of chapter 2 and 3 and the knowledge created through the primary research for chapter 5.
- Chapter 5 combines the knowledge about the external influences and the internal environment of chapters 2 to chapter 4 by implementing the MCDA method. All input data revealed via primary and secondary research is provided. The results are presented to expose how current electricity sources perform in comparison to hybrid versions with selected renewables. In addition, a sensitivity analysis to key input data was conducted.
- Chapter 6 represents an overview of the results. The chapter is structured according to the research objectives in Figure 1.2. A section is written entailing the created and gathered knowledge for each objective of this study. Lastly, suggestions are made as to how this study can be extended in future research.

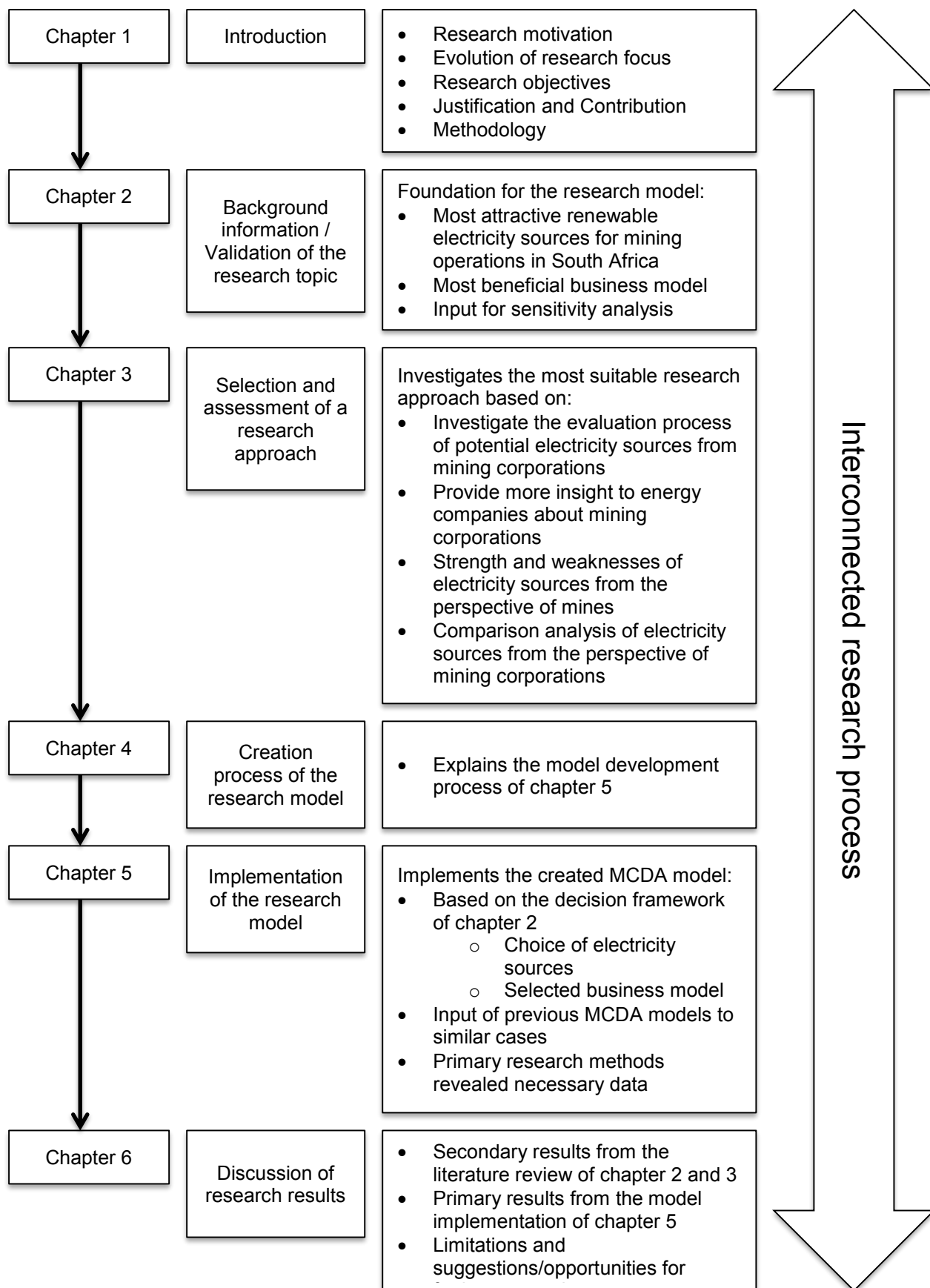


Figure 1.5: Research overview

Chapter 2 A literature review on the potential of renewable electricity sources for mining operations in South Africa³

2.1 Introduction

This chapter provides a literature review to analyse the potential and influences on the market of renewable electricity sources for mining corporations in South Africa. The elements were chosen in accordance with mining and energy companies participating in this study. As can be seen in the research objectives of this chapter in Figure 2.1, the investigation indicates how renewable sources could possibly fit into the operations of mining locations. Secondly, the technological attractiveness of different renewable and current sources is examined. Thirdly, the potential of different business models is investigated. Fourthly, additional influences on the market are investigated.

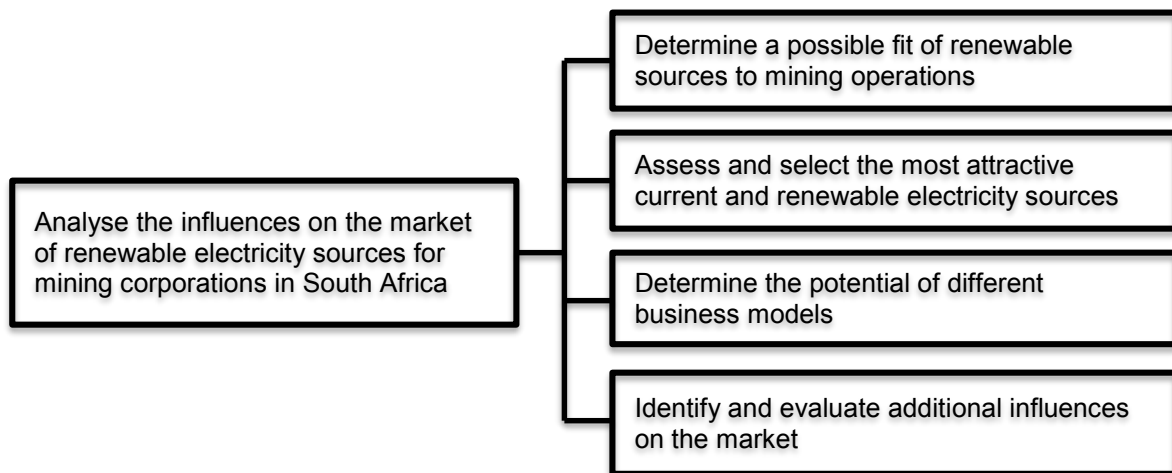


Figure 2.1: Research Objectives of chapter 2

During the thorough literature search, no previous study combining a comprehensive selection of elements that influence the project realisation of renewable electricity projects with mining corporations in South Africa came to light. However, three papers – by Boyse et al. (2014); Gets and Mhlanga (2013); Brodsky, Curnow, Fevre, Ghannam, Nasrollah and O'Brien (2013) – do cover some of the elements.

³ The chapter originates from an article, which was prepared for the *Journal of Energy in Southern Africa*.

2.2 Mining operations

2.2.1 South African Landscape

South Africa is the second biggest economy on the African continent according to a GDP of €3,18 Billion in 2014. The GDP of Nigeria surpassed the South African in 2011 (World Bank Group, 2015c; Statistics South Africa, 2015a). Since 2013, the mining sector in South Africa contributed about 8% to the GDP with a long-term downward trend since 1970 from 21%. Despite the decline in growth rate of real investment, mining is still responsible for near 19% of private sector investment. Today, the mineral sales exports account for 30% of South Africa's total merchandise export (Chamber of Mines, 2014).

The electricity crisis, including power outages, caused by Eskom contributed to the drop in economic growth by 1,5% to 3,5% in 2008. The mining sector suffered the most and plunged by 22,1% in the first quarter of 2008. The Eskom crisis in 2015 caused the economic growth to contract by 1,3% in the second quarter to 1,2%. The production of the mining sector decreased by 4,8% from 2014 to 2015 (Maasdam, 2008; Statistics South Africa, 2015b). Yet, as illustrated in Figure 2.2, South Africa still has one of the most reliable electricity supplies in Sub-Saharan Africa.

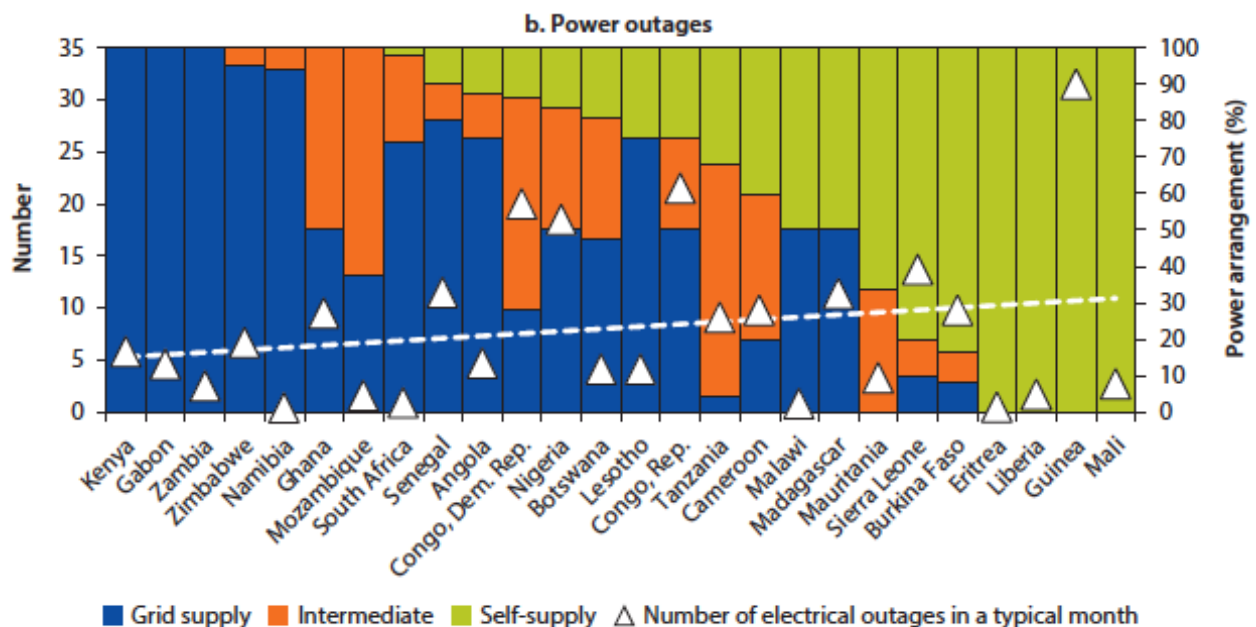


Figure 2.2: African comparison of security of electricity supply

(Source: Banerjee et al., 2015)

Eskom's megaflex tariff has increased by 346% from €1,13 cents (ZAR15,74 cents) in 2007 to €5,05 cents (ZAR70,35 cents) in 2015. The tariff is commonly charged to mines

due to their high consumption. For illustration purposes, the standard tariff of the high demand season, with less than 300km transmission zone and a supply voltage of less than 132kV was used. However, as can be seen in Figure 2.3 South Africa still has one of the cheapest tariffs. The numbers originate from 2014.

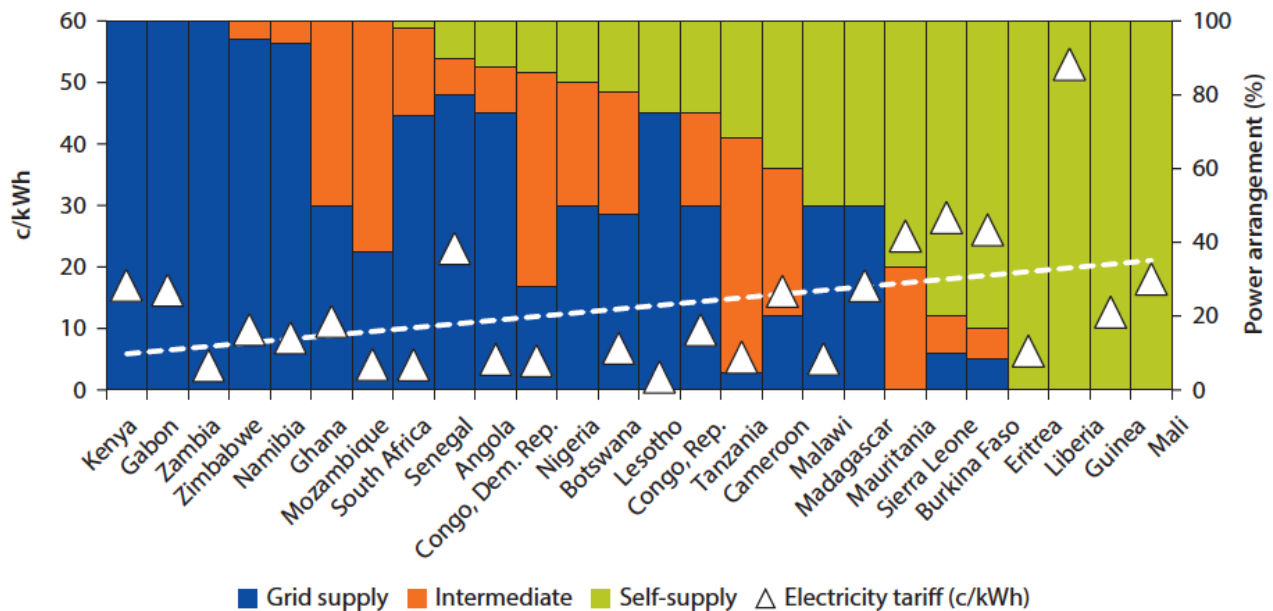


Figure 2.3: African comparison of electricity tariffs for mines firms

(Source: Banerjee et al., 2015)

For descriptive purposes, the average percentage of annual expenditure on electricity costs for members of the EIUG⁴ has risen from 7% in 2007 to 20% in 2014, of which 47% are mining companies (EIUG, 2014b). Power rarely constitutes less than 10% of mining operating costs and often exceeds 25% (Banerjee et al., 2015). Based on the high electricity reliance, the rising prices will have a negative impact on the global competitiveness of the companies (Mathaba et al., 2014). The South African mining sector consumes 15% of Eskom's annual output. Within the mining industry, the gold mining sector, which is the biggest user, consumes 47%, followed by platinum, which consumes 33%, and all other commodities combined consume the remaining 20% (Eskom, 2010).

The South African power sector has an installed generation capacity of 45GW, which is more than half of the whole of Sub-Saharan Africa with 80GW. Nigeria is in second place with 6GW (Williams, 2014). The substantial and growing need for power for mining

⁴ Energy Intensive User Group (EIUG) of Southern Africa (2014a) is a non-profit organisation whose members are energy intensive consumers – of which 47% are involved in mining and quarrying.

corporations can assist to improve the energy resources, as anchor consumers. As high volume customers, they provide a captive source of demand and a consistent revenue stream. The projected growth rate for the mining industry until 2020 is 3,5%, which is relatively low in comparison to other Sub-Saharan African countries with 9,2% (Banerjee et al., 2015).

Nevertheless, the previous mentioned increase in tariffs and insecurity of supply by Eskom is moving more and more mines in South Africa towards greater independence and self-supply (Deloitte, 2012). Mining corporations are at least as concerned about security of supply as they are about costs. Investment in self-supply to ensure control and continuous power availability, even when the costs per kilowatt delivered is much higher is not rare. Figure 2.4 indicates that the electricity demand of the South African mining sector is predicted to consume nearly 10GW in 2020. This fuels the discussion as to whether Eskom is able to satisfy this demand or if an increasing number of mines are going to be self-supplied (Banerjee et al., 2015). This development combined with the economical progress of renewable sources (section 2.3) provides further substantiation for this study and to why mining corporations could benefit of diversifying their electricity mix.

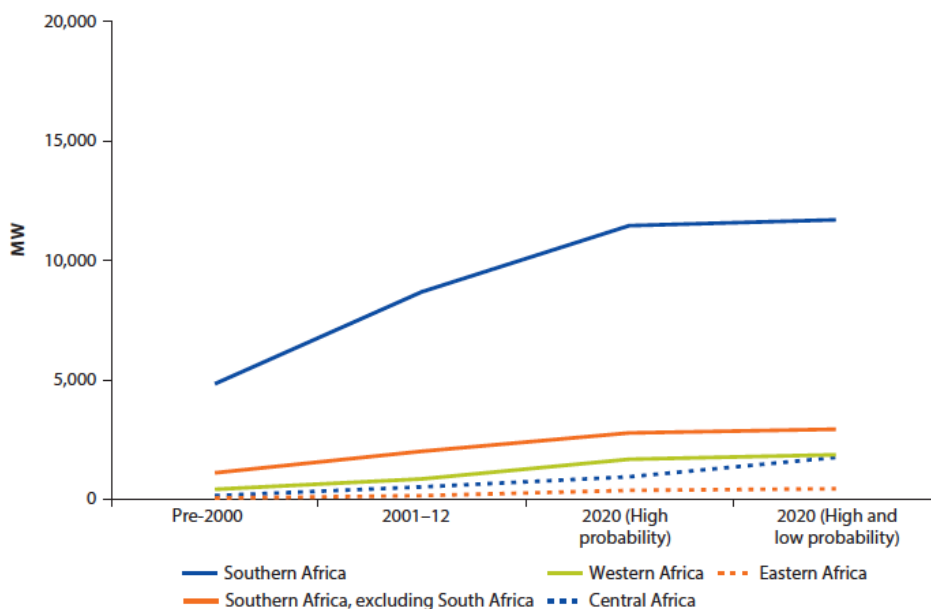


Figure 2.4: Prediction of mining power demand until 2020
(Source: Banerjee et al., 2015)

2.2.2 Electricity pattern of mining operations

The purpose of this section is to provide the background knowledge of the processes and influences that determine and shape the electricity demand patterns of mining operations. Before focusing on the technological aspects, it is important to state that mining corporations are big and slow-moving entities. The concept of renewables being used by mining operations has only developed in recent years through economic and technological progress. However, the current development of lower commodity prices hinders the widespread adoption of renewables, as falling profits and lower fuel prices maintain barriers (Crespo, 2015c). In addition, the long-term investment into renewables is hindered by the investors' pressure for short-term capital appreciations (Elliott, 2014). Therefore, one of the main outcomes of several renewables and mining summits⁵ worldwide is the fact that mining corporations have to be better educated about the concept of renewable sources in the context of their particular operational demands (Judd, 2014b).

The electricity consumption patterns have great influence on the selection of electricity sources (Klein and Whalley, 2015). The majority of mining locations operate day and night, which often creates a relatively constant baseload demand (Levesque et al., 2014). The required amount of electricity depends on the type of mineral and even more on the extent of processing or beneficiation. The electricity needed to completely beneficiate a mineral such as Copper or smelt Aluminium can be several times the amount required for simple digging, crushing and sorting. The basic and intermediate process for Nickel, Cobalt and Copper is very electricity intensive (Banerjee et al., 2015).

Every type of mineral mined has its specific processes, and it is not necessary for all to undergo all processes to be ready for use in manufacturing. The main processing stages are as follows (Banerjee et al., 2015):

- Extracting the resource by digging, sorting and crushing – generally known as mining
- Concentration of the mineral using various techniques. The majority is either based on gravity or comprises a chemical process to separate elements or uses magnetism to separate waste from the mineral
- Smelting of the concoction at high temperatures to separate the slag from the metal
- Refining, often through electrolysis, to achieve a higher level of purity

⁵ Summits of mining corporations and renewable energy companies started in 2013, to develop and discuss the market of renewables in mining operations (Energy and Mines, 2015).

Figures 2.5-2.7 are based on a database of 168 mining operations in Africa (World Bank Group, 2015a). Figure 2.5 provides an overview of the cumulative power requirements for mining operations at stages of beneficiation. The Platinum group, Gold and Aluminium is by far the most electricity intensive one. Gold and Platinum is illustrated in ounce and it needs 35273oz to fill up one tonne (Metric Conversion, 2015). Nickels, Ilmenite, Cobalt, Copper and Chromium also have a relatively high electricity demand with a more mixed consumption profile.

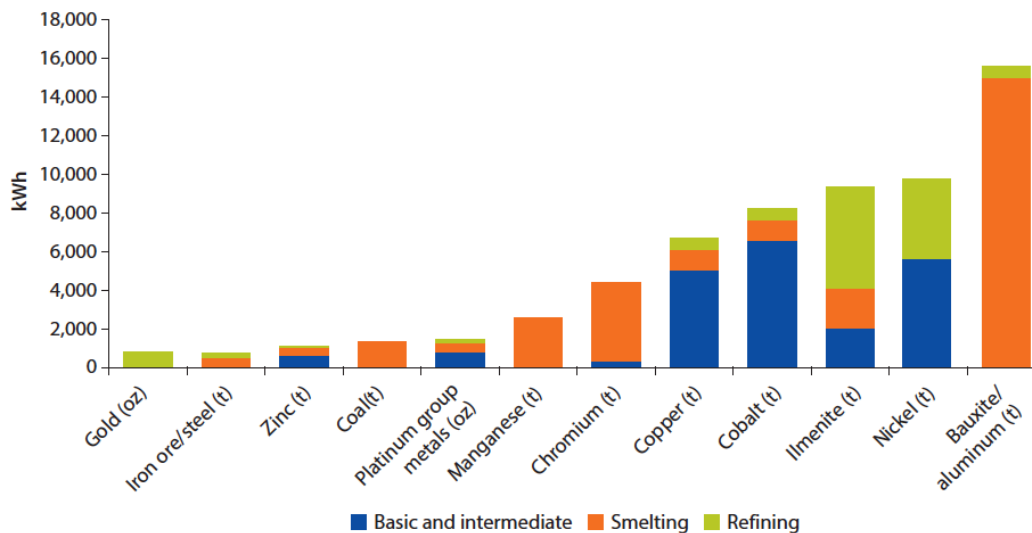


Figure 2.5: Cumulative power requirements at stages of beneficiation

(Source: Banerjee et al., 2015)

The overall contribution in the different periods to the mining electricity demand can be seen in Figure 2.6. The smelting and refining processes are the most electricity intensive and were responsible in all periods for more than three quarters of the demand. The South African mining industry is the most electricity intensive one in Sub-Saharan Africa, with 70% of the demand in the year 2000 and 66% in 2012.

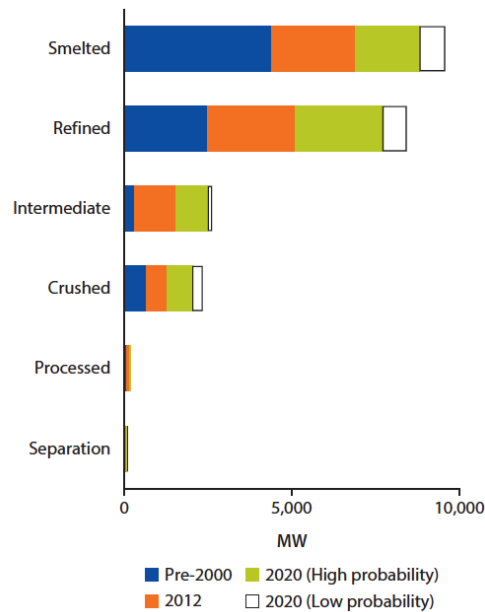


Figure 2.6: Electricity demand by processing stage

(Source: Banerjee et al., 2015)

Another factor affecting the electricity demand is whether the mining operations are underground or at the surface. Underground mining operations require significantly higher quantities of electricity than surface mining, due to a great rise in hauling requirements, ventilation, water pumping and other operations (Toledano, 2012). Figure 2.7 provides an indication of the difference in electricity demand for Coal, Copper, Gold and Platinum. It can be seen that surface mining uses between 30%-40% less electricity.

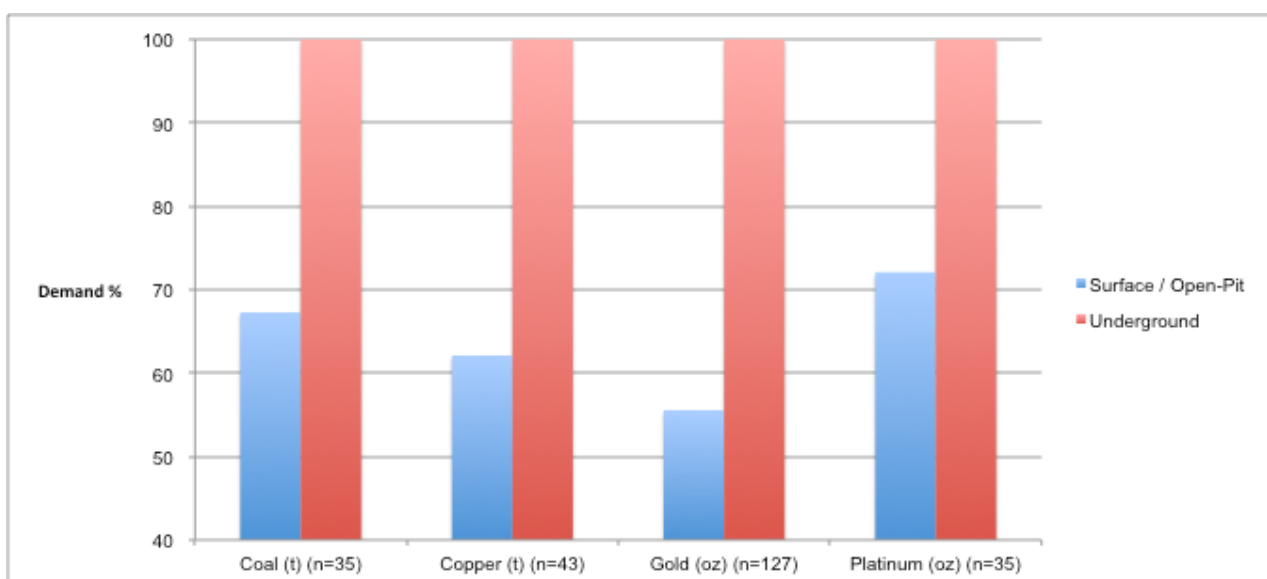


Figure 2.7: Underground and surface mining electricity demand

(Based on: World Bank Group, 2015a)

2.2.3 The demand profile

This section and the following one introduce the 24hour demand profiles of five different mining operations in South Africa. The first one is extracted from an Article of the *Journal of Energy in Southern Africa* and the other four are from mines, which were participating in this study (see section 4.1.1 / Table 4.1). The purpose is to gain a better understanding of the consumption patterns and how renewable electricity sources could fit in. The sample includes different types of mines to provide a better overview.

The demand profile in Figure 2.8 illustrates the electricity consumption pattern of an underground grid connected gold mine in South Africa. It is interesting to note the relatively constant 24hour electricity demand with two visible reductions at round 9am and 7pm. The purpose of these reductions is both to save costs and shift loads to other times if possible. The shifting of consumption is done because of the megaflex tariff structure of Eskom, which is used for large electricity consumers and is more expensive at these times as can be seen on the price signal line. Eskom's demand response program offers large customers an opportunity to reduce their demand when requested in return for financial rewards, which improves grid stability (Williams, 2014). This Demand Side Management (DSM) strategy is commonly used in South Africa to lower operating costs, by optimizing time schedule of systems like pumping and refrigerating (Mathews, 2005).

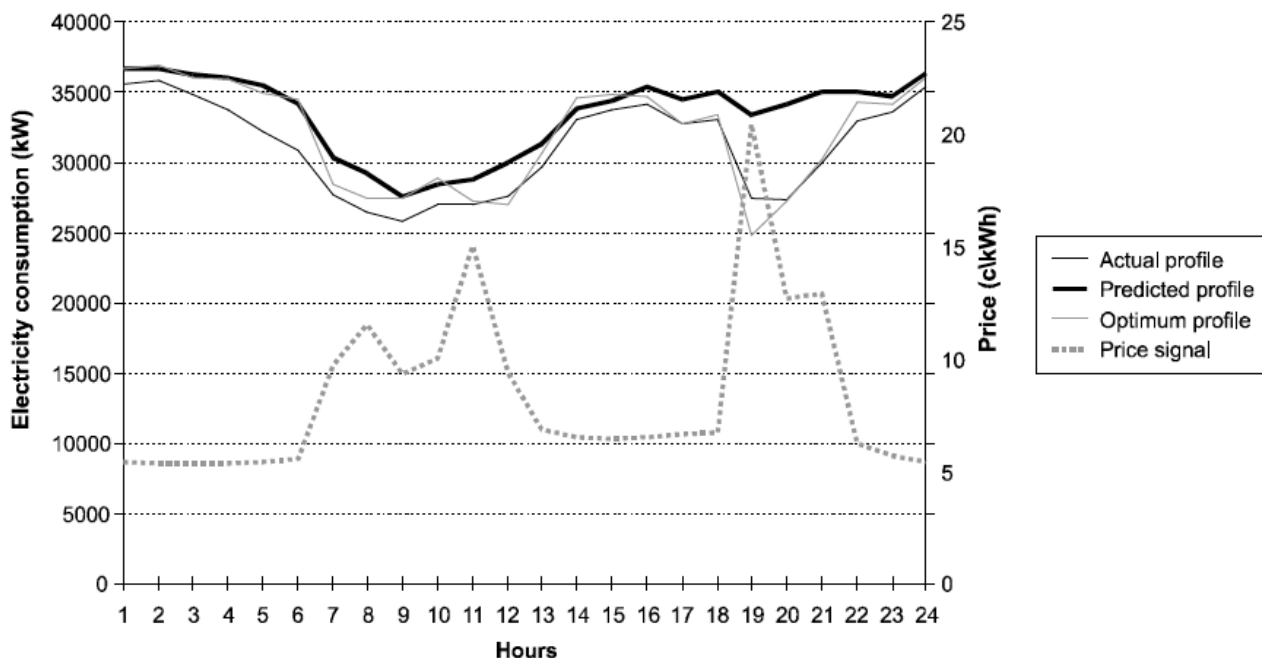


Figure 2.8: Electricity demand profile of an underground gold mine
(Source: Mathews, 2005)

Figure 2.9 illustrates an average weekday and Sunday consumption profile of a large grid connected underground gold mine in South Africa. The purpose of the consumption reduction around 9am and 7pm is again to save costs by shifting demand to other times (Wouter, 2014). Despite the two reductions, the day and night electricity consumption is relatively constant.

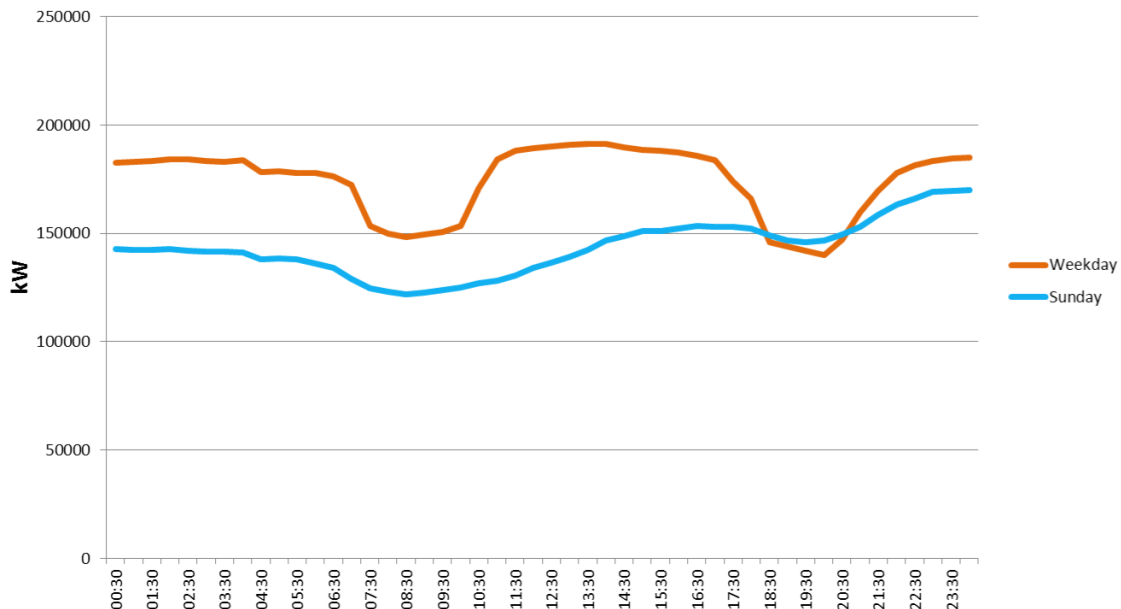


Figure 2.9: Electricity demand profile of an underground gold mine

(Source: Wouter, 2014)

The demand profile in Figure 2.10 illustrates the 24hour electricity usage of an underground grid connected coal mine in South Africa. The usage dip between 2am and

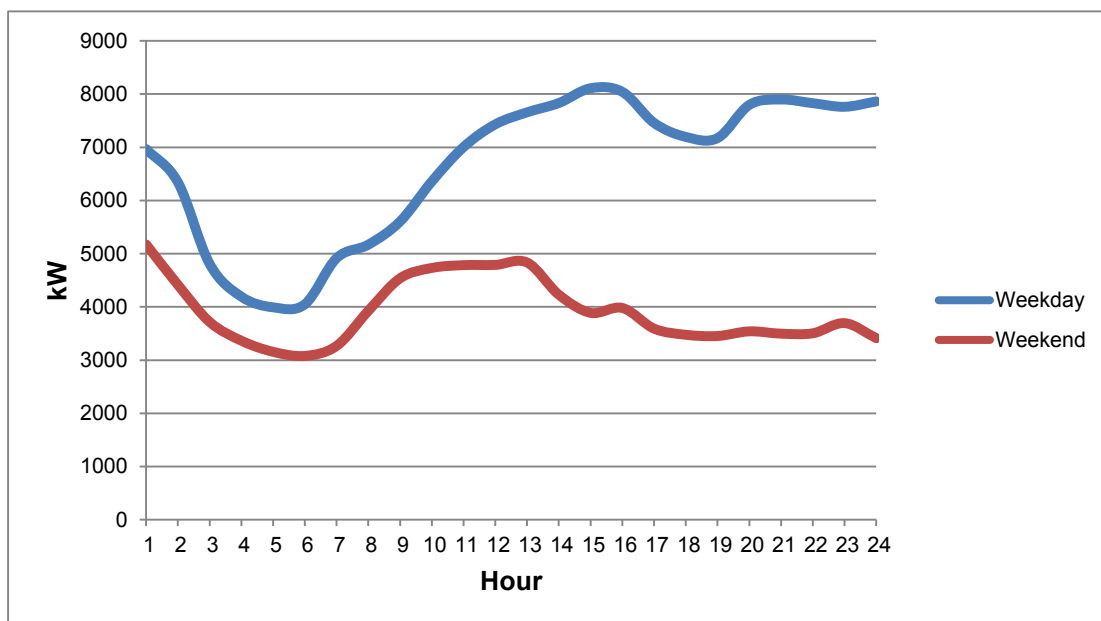


Figure 2.10: Electricity demand profile of an underground coal mine

(Source: Van Staden, 2015)

7am is due to the operating processes and not because of a DSM strategy. However, the reduction at 6pm is as a result of load shifting to reduce costs. As in Figure 2.10, it can be seen that the consumption on weekends is lower than during the week (Van Staden, 2015).

The electricity demand profile of the third mine participating in this study does not exist in form of a graph, as the consumption is not recorded on an hourly basis. The operation is not grid connected and runs on diesel generators day and night. The 24hour consumption is very constant. The mining is conducted on the surface and the main mineral extracted is Zircon (Beukman, 2015).

As mentioned in section 2.2.2, mining operations are commonly conducted at day and night to optimize the process (Levesque et al., 2014). The demand profiles illustrated entail three underground and two surface mines. The underground operations were two gold and one coal mine of which all three are grid connected. The surface operations are Chromium ore and Zinc mines, which run on diesel generators.

Four demand profiles in this section and in Figure 2.12, in the next section, show relatively constant 24hour consumption. The profile in Figure 2.10 has only one reduction in the early morning to half the amount after midday. The mine still uses 3MW at the lowest point of the curve. Consequently, the fundamental prerequisite for an electricity source to be suitable for a mining location is its baseload capacity to be able to cover the electricity need for 24 hours a day. The intermittency of most renewable sources like wind or solar photovoltaic (PV) renders it impossible to use these sources individually to cover the electricity demand of mining operations (Judd, 2014a; Mostert, 2014).

Based on the literature demand profiles introduced and the investigative nature of this research, a consistent demand profile is assumed for the rest of the study. Indeed, as stated in section 6.5, opportunities for further research should apply this knowledge to selected mines and their own demand profiles.

2.2.4 Hybrid concepts

This section introduces the concept of hybrid solutions in accordance with the demand profile of mines introduced in the previous section. Indeed, it is difficult to generalize to all

mining operations as every profile has its own characteristics. However, the concept of a 24hour demand with a relative constant usage is provided in the previous section.

There are three technical options that have to be considered for renewable sources with lower capacity factors at mining locations: renewables with storage; a hybrid system; and a hybrid system with storage. A detailed report on the opportunities of renewables at mining locations in South Africa (Boyse et al., 2014) identified a hybrid version combined with a baseload capacity source as most cost effective. The model recommended is that the supply/demand profiles have to be optimized, which means that all renewable energy goes to the primary load. Ideally, at peak output, the supply should not exceed the mines demand. Grid-connected mining operations can add a single renewable source for purposes like decreasing costs, increasing independence and lowering CO₂ emissions (Levesque et al., 2014). The diesel generator/Eskom supplies on a full-time basis and renewable sources reduce the net load. Start-up current spikes of diesel generators are handled with surge protection devices to prevent damage to equipment (Gan et al., 2015; IRENA 2013a). This problem is limited as generators run on a full-time basis.

The basic principle of a hybrid system is illustrated and explained by using an example, based on the first and only project in South Africa in Figure 2.11. The hybrid project can also be realised with other renewable sources like wind. In case of a grid-connection to Eskom, it is possible, for example, to replace the diesel generator (Wirth, 2015).

The demand profile of the first renewable electricity project at the non-grid-connected Cronimet Chrome Mining's Thaba mine north-west of Johannesburg, which was finalized at the end of 2012, is presented in Figure 2.12. The technical details provide further understanding of how the first project is adding value to the mining operation. The project is a hybrid solution, and uses a 1 MW PV system (60% penetration ratio) and a 1.6 MVA diesel generator, which provides the back-up electricity. The time span for the project from conception to commissioning took 6 months. The initial capital outlay was €2,42⁶ million for the PV plant in 2012, with annual 1% operating and maintenance costs. The annual diesel burn was 1.9 million litres, of which 450.000 litres can be saved through the solar PV plant. It was calculated that the breakeven point would be achieved at 3.6 years owing to the savings on diesel. The calculation included the assumption of an annual 12% diesel

⁶ For the purpose of this study the following exchange rates from the 13.07.2015 were used: EUR1=USD1,10 (CNN Money, 2015a); EUR1=ZAR13,94 (CNN Money, 2015b)

inflation rate on initially €1.05 per litre. The net present value was calculated at €2,86million, with a discount rate of 15% and a lifetime of 20 years (Ambros, 2014).



Figure 2.11: Principle of a hybrid system

(Source: Boyse et al., 2014)

The demand profile in Figure 2.12 is relatively constant with a slight increase between 8am and 5pm; the sudden drop at 11am is due to operational processes. As stated in the beginning of this section, the general solar peak supply does not exceed the mining demand. The solar PV profile represents a clear sky throughout the whole day. As the solar PV generation increases, the diesel generator production is decreasing and vice versa. It is important to mention that the diesel generator has a lower load limit of 25% to prevent damage. Below this limit the generator suffers from poor combustion that reduces efficiency, increases maintenance costs and can cause permanent damage that reduces the life span. A control unit is managing the supply levels of solar and diesel generator

(IRENA, 2013a). A hybrid version with Eskom requires only a 5% minimum load to keep the electricity supply stable (Wirth, 2015).

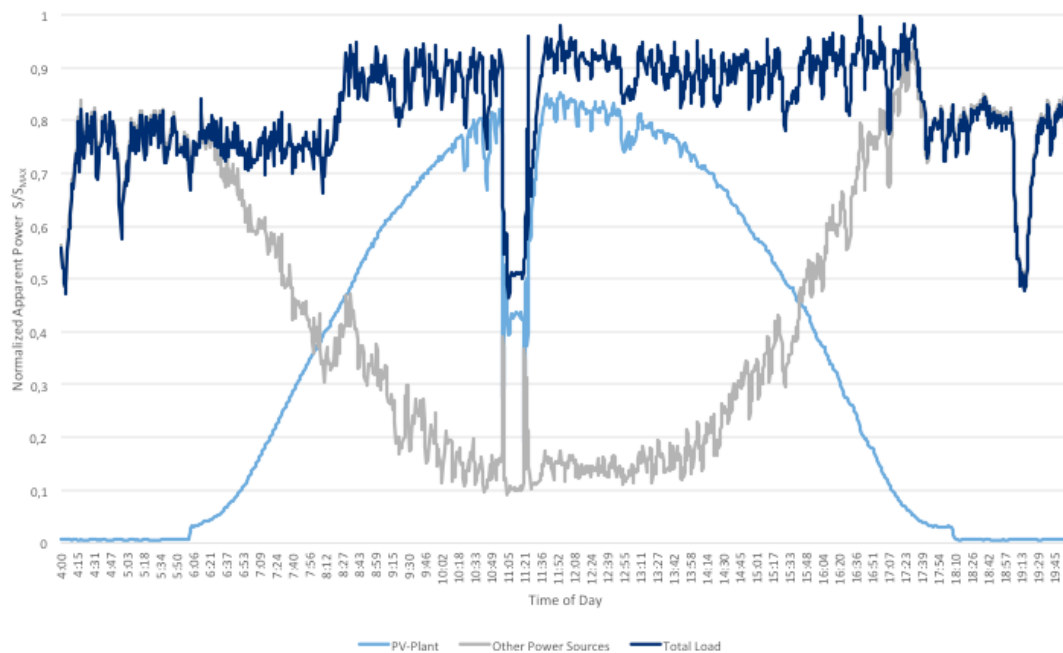


Figure 2.12: Electricity demand profile of a surface chromium ore mine
(Source: Wirth, 2015)

The principles for hybrid versions with wind and geothermal power are very similar. The reasoning for selecting the three renewable sources is explained in more depth in section 2.3. However, the different generation profiles have to be considered. Wind generation is possible throughout 24 hours. Variations between no wind and strong wind are possible, which makes it important to create a wind profile of the area through measurements (Rehman et al., 2012). In contrast, geothermal energy is not dependent on the weather and has a constant 24hour electricity output. Both sources require lower spinning limits for a diesel generator due to their more constant supply levels, as PV generation can be strongly interrupted by clouds (Wirth, 2014).

2.2.5 A global overview of existing projects

Worldwide, 21 operating renewable energy projects were identified. The 22 projects are introduced and categorised in Table 2.1. The market is relatively young with the first wind project being commissioned in 2010 and the first solar project in 2012. An overwhelming 91% of the electricity sources are solar PV ($n=11$) and wind ($n=8$) installations. Half the projects are in Chile, of which the majority are grid-connected and financed through a power purchase agreement. Table 2.1 shows the projects that are not connected (1-12)

and those that are connected (13-21) to their countries' national grids. The following conclusions can be drawn:

Off-grid projects

- Can be found in various countries;
- Seven out of 12 are based on the mining corporation's own investment; and
- The largest project is 9,2 MW.

On-grid projects

- Eight out of 10 are in Chile;
- 90% are financed through a power purchase agreement; and
- Sizes range up to 115 MW.

The table provides several indications, which are important for the following process of the study. Firstly, in regards to the business model (section 2.4) the majority of off-grid projects are based on own investment. In addition, none of these projects is larger than 10MW, which also contributed to the selection of project size for the model creation in chapter 5. Lastly, the type of renewable energy source used provided backup for the selection of technologies for the model creation. The names of the companies involved were stated to provide a comprehensive illustration.

Table 2.1: Global operating renewable energy projects at mining locations

Number	Mining cooperation	Mine	Developer	Financing	Connection	Location	Size	Source	Date of first operation	Reference
1	Antofagasta Minerals	El Tesoro	Soitec Solar	Own investment	Off-grid	Chile	0,06 MW	CPV	2013	(Soitec, 2015)
2	Royal Gold	El Toqui	Vergnet	Own investment	Off-grid	Chile	1,65 MW	Wind / Hydro / Diesel	2010	(Vergnet Wind Turbines, 2014)
3	Rio Tinto	Diavik	Enercon	Own investment	Off-grid	Canada	2,3 MW	Wind / Diesel	2012	(Enercon, 2015)
4	Cronimet Mining AG	Thabazimbi	Cronimet Power Solutions	Own investment	Off-grid	South Africa	1 MW	Solar PV / Diesel	2012	(Cronimet Power Solutions, 2015)
5	Galaxy Resources	Mt Cattlin	Swan Energy	Own investment	Off-grid	Australia	3,6 MW / 1 MW	Wind / Solar PV / Diesel	2012	(Galaxy Resources, 2015)
6	Barrick Gold	McCarran	Stellar Energy	Own investment	Off-grid	USA	1,51 MW	Solar PV / Gas	2014	(Stellar Energy, 2013)
7	Glencore	Reglan	Enercon	Own investment	Off-grid	Canada	3 MW	Wind / Diesel	2014	(Glencore, 2015)
8	Mandalay Resources	Cerro Bayo	Rame Energy	PPA	Off-grid	Chile	1,8 MW	Wind / Diesel	2015	(Rame Energy, 2014)
9	Barrick Gold	Veladero	Rame Energy	PPA	Off-grid	Argentina	2 MW	Wind / Diesel	2014	(Rame Energy, 2014)
10	Rio Tinto	Weipa bauxite	First Solar	PPA	Off-grid	Australia	6,7 MW	Solar PV / storage / Diesel	2014	(First Solar, 2015)
11	Rio Tinto / Dominion Diamond Corporations	Lac de Gras	ENERCON Canada	Joint Venture	Off-grid	Canada	9,2MW	Wind / Diesel	2012	(Rio Tinto, 2015)
12	Shanta Gold	New Luke	Redavia Solar	Rental	Off-grid	Tanzania	1 MW	Solar PV / Diesel	2014	(Redevia, 2015)
13	SNIM	Nouadhibou	Vergnet	Own investment	On-grid	Mauritania Nigeria	4,5 MW	Wind	2012	(SNIM, 2013)

14	Antofagasta Minerals	Los Pelambres	Pattern Energy	P PA	On-grid	Chile	115 MW	Wind	2014	(Pattern Energy, 2015)
15	Antofagasta Minerals	El Tesoro	Abengoa	PPA	On-grid	Chile	10,5 MW	CSP	2012	(Abengoa Solar, 2015)
16	Xstrata / Anglo American	Collahuasi	Solarpack	PPA	On-grid	Chile	25 MW	Solar PV	2012	(Solarpack, 2012b)
17	Quiborax	El Aguila	E-CL	PPA	On-grid	Chile	2,3 MW	Solar PV	2013	(E-CL, 2015)
18	Barrick Gold	Punta Colorada	Rame Energy	PPA	On-grid	Chile	20 MW	Wind	2011	(Rame Energy, 2014)
19	Imagold	Rosebel	Renewable Energy Resources Corporation	PPA	On-grid	Suriname	5 MW	Solar PV	2014	(Renewable Energy Resource Cooperation, 2014)
20	Antofagasta Minerals	Chuquicamata	Solarpack	PPA	On-grid	Chile	1 MW	Solar PV / Diesel	2012	(Solarpack, 2012a)
21	Minera Dayton	Andacollo	Solairdirect	PPA	On-grid	Chile	1,26 MW	Solar PV	2013	(Solairdirect, 2012)
22	CAP Group	Copiapo	Sunedison	PPA	On-grid	Chile	100 MW	Solar PV	2014	(Sun Edison, 2013)

2.3 Attractiveness of electricity sources

This section discusses technological factors of currently used and possible renewable electricity sources for mining operations in South Africa. Table 2.2 represents an overview of the results. The purpose is to compare current sources to renewable sources and to indicate which renewable sources are most suitable for South Africa.

Table 2.2: Electricity-generating technologies for South African mines

	Initial investment €/kW	LCOE €/kWh	Capacity factor in %	Annual price forecast until 2020	Experience	Availability of power / fuel source	Service infrastructure	Project size 1-10 MW
Diesel generator ^{1,2,3,4,5}	450–720	0,31–0,36	≈95	8% increase	Excellent	Good	Very good	Yes
Eskom ^{16,17,18,19}	360–405	0,063–0,067	≈99	12% increase	Excellent	Good	Very good	Yes
Solar PV ^{1,6,7}	1350–1800	0,065–0,19	<30	3,4% decrease	Good	Good	Very good	Yes
CSP ^{1,6,7,8,9}	3150–7830	0,16–0,27	<80	3,5% decrease	Limited	Medium	Good	Not commercial
Wind on-shore ^{6,7,10}	1170–1980	0,054–0,1	<48	2% decrease	Good	Medium	Very good	Yes
Geothermal ^{7,12,15,16}	2700–4950	0,072–0,13	<90	0%	No	Medium–Good	Low	Yes
Biomass ^{2,6,13}	2340–4050	0,036–0,13	<80	0%	No	Medium–Low	Low	Yes
Battery storage ^{1,15}	1800–3600	0,38–0,54		10,6% decrease	Limited	/	Low	Yes
Hydro power ^{2,6}	1350–3150	0,036–0,13	<60	0%	Limited	Medium–Low	Medium–Low	Yes
(1) Lazard, 2014; (2) IEA, 2014; (3) Gielen, 2012; (4) OPEC, 2014; (5) World Bank Group, 2015b; (6) IRENA, 2015a; (7) IRENA, 2014c; (8) Hinkley, et al., 2011; (9) Fichtner, 2010; (10) Fraunhofer, 2013; (11) MAKE Consulting, 2013; (12) Tshibalo et al., 2015; (13) Bole-Rentel and Bruinsma, 2013; (14) IRENA, 2015b; (15) IEA, 2011; (16) Ngugi, 2012; (16) DOE, 2013; (17) GIZ, 2014; (18) Fouche, 2013; (19) Wernecke, 2015.								

Two types of technical factors were selected. These were identified according to the main factors used to analyse electricity sources in the papers investigated for Table 2.2. Only

experience and project size were added to the specifications of this research. The project size refers to the anticipated demand of the mine. Consequently, for all sources except Eskom, project size relates to the actual size of the project. In the case of Eskom, project size refers to the possibility of building the transmission lines. The first type provides indicative data for generating technologies, namely initial investment costs, levelized⁷ costs of energy (lcoe) and capacity factor.

The second type indicates the suitability for the purpose of mining operations in South Africa. The selected factors are: the experience with the source in the global mining industry, the availability of the energy source or fuel in South Africa to power the system, the service infrastructure in South Africa, and the possibility to realise medium-scale projects of 1 MW to 10 MW. The location of mining regions in South Africa is indicated in Figure 2.13. This will give a better understanding of the natural fuel availability to power the renewable technology.

The conventional electricity sources at mining operations in South Africa are diesel generators and a grid connection to Eskom. Gas generators were not selected as the fuel supply infrastructure in South Africa is not sufficient and is currently not used by South African mines (Boyse et al., 2014; IRENA, 2015c). The black blocks on the maps indicate the mining areas where the source can be used. The non-renewable and renewable electricity-generating technologies, which have the potential to be used on-site or via grid-connection by mining corporations are introduced briefly here below:

- Diesel generator

The usage of diesel generators at mining operations in South Africa is common. The reason for this is their high reliability due to solid service and fuel infrastructure. Projects of all sizes can be executed, according to the need of the mine (Global Data, 2014). The average annual diesel price increase is a combination of the forecasted global real annual increase of 2% (OPEC, 2014; World Bank, 2015b) and a South African average annual inflation rate of 5% (IMF, 2014; OECD, 2014).

⁷ This method considers the predicted lifetime-generated energy and estimates a price per unit of electricity produced (Branker et al., 2011). The different sources assumed: share of equity of 20–40%; share of debt of 60–80%; cost of capital of 8–10%; cost of debt of 6–8% and a lifespan of 20–25 years.

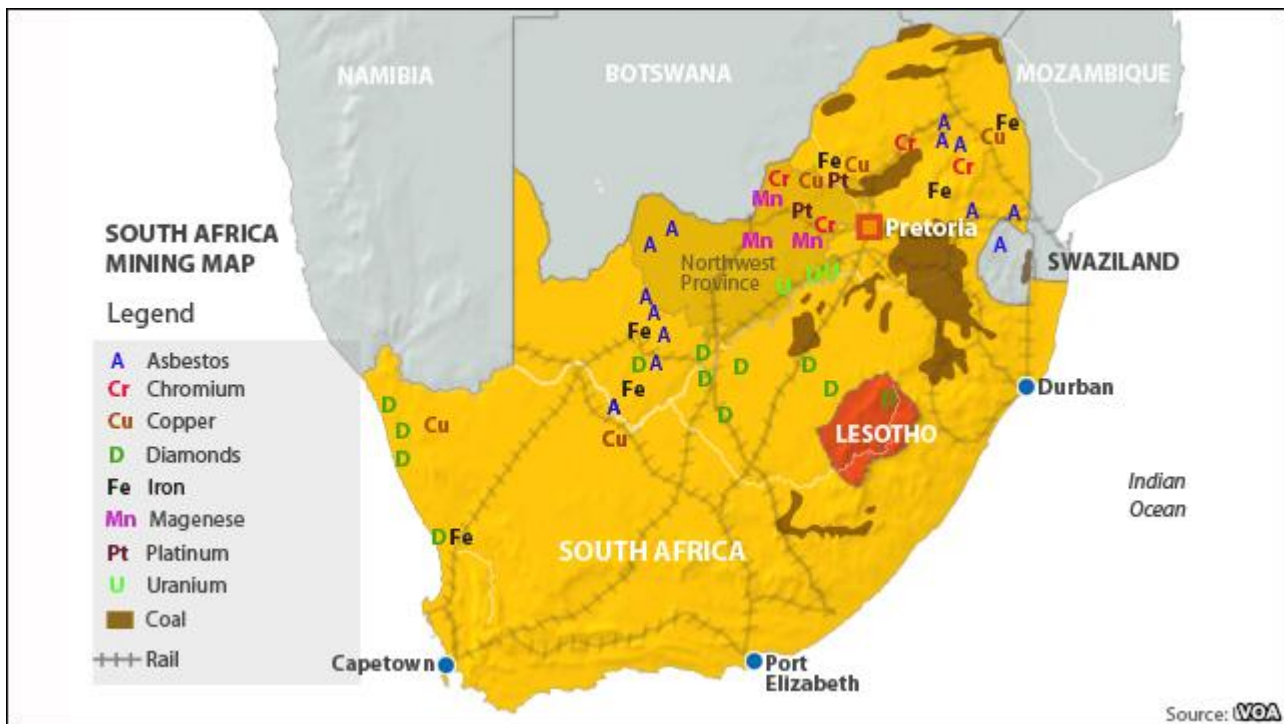


Figure 2.13: Mining map South Africa

(Source: VOA News, 2012)

- Eskom

Eskom is responsible for South Africa's electricity production. The country's electricity is produced with coal-fired plants (93%), renewables (1%), pumped storage (1%), gas (1%) and nuclear power (5%) (Eskom, 2014). Since the first power crisis in 2008, Eskom has been struggling to cover the nation's electricity demand with the present sources of electricity. Load shedding was conducted in 2008 and 2014/2015 (Eskom, 2015c). Eskom has special pricing deals with mining corporations like BHP Billiton, which pays between €0,027/kWh and €0,036/kWh (Yelland, 2013).

Eskom's experience and practical knowledge is extensive as numerous mines use it as a supplier (Boyse et al., 2014). The availability of Eskom as a source can be seen in Figure 2.14. The thin lines represent the power grid (availability of power source), which is not ideally developed in the central and western regions. The service infrastructure is well established since Eskom owns the national grid. Applications can be made for medium- (1-10MW) and large-scale (10MW<) connections (Eskom, 2015f).

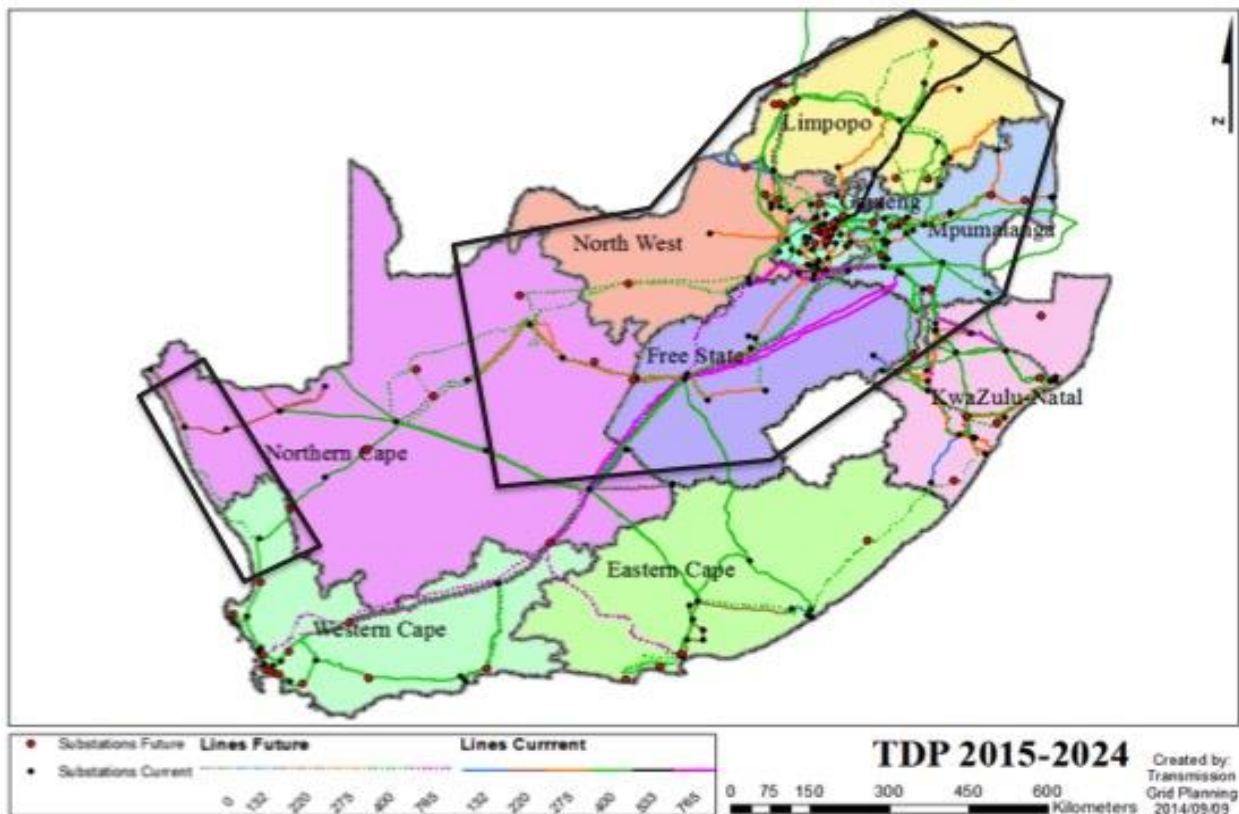


Figure 2.14: Eskom power stations and grid

(Source: Eskom, 2013)

- Solar photovoltaic

The data for solar photovoltaic (PV) technology are based on single-axis tracking devices. The global experience with solar PV technology at mining operations is considerable (see Table 2.1). The areas with high mining activity are indicated in Figure 2.15; the majority have an annual radiation of more than 2 000 kW/m². The modular technology enables medium-sized projects. The service infrastructure is well established owing to an established market in South Africa (SAPVIA, 2013b; Global Data, 2014).

- Concentrating solar power

The data presented for concentrating solar power (CSP) are based on the technology of parabolic trough with synthetic oil and power tower with molten salt, as both technologies are commercially proven and available (Gauché et al., 2014). The initial investment is strongly positively correlated with the capacity factor. The global experience with CSP and mining operation is limited, with one grid-connected project in Chile (see Table 2.1). The sun radiation in mining areas shows high potential to use CSP as a power source, as discussed under solar PV in Figure 2.15. The service

infrastructure is established with several companies in South Africa, which have realized seven projects (NREL, 2015). Projects of up to 10 MW exist, but are not commercial as costs are too high (Fraunhofer ISE, 2013).

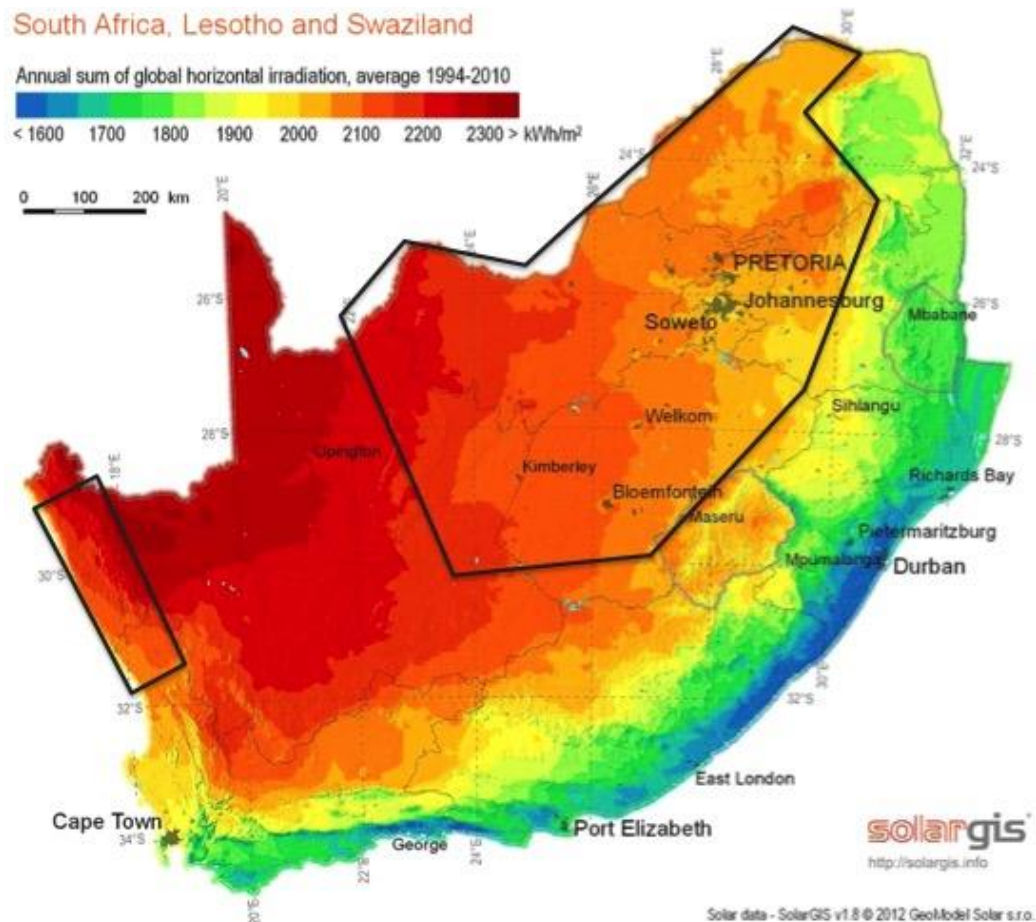


Figure 2.15: Solar resource quality across South Africa
(Source: Walwyn and Brent, 2015)

- Wind power

For the purpose of this chapter, only on-shore wind technology was considered. This is because the majority of mining locations are not in coastal regions as can be seen in Figure 2.13 and 2.16. The international experience with wind and mining operations is advanced, with nine established off- and on-grid projects (see Table 2.1). Figure 2.16 illustrates mining areas with the highest wind potential in South Africa. The overall power availability is medium as wind conditions in the centre of South Africa are less favourable in general (DTI, 2015). The service infrastructure in South Africa is well established as several wind farms have been established and the responsible companies are located in the country. Projects can be realised on a small to utility scale (IEA, 2014; SAWEA, 2015).

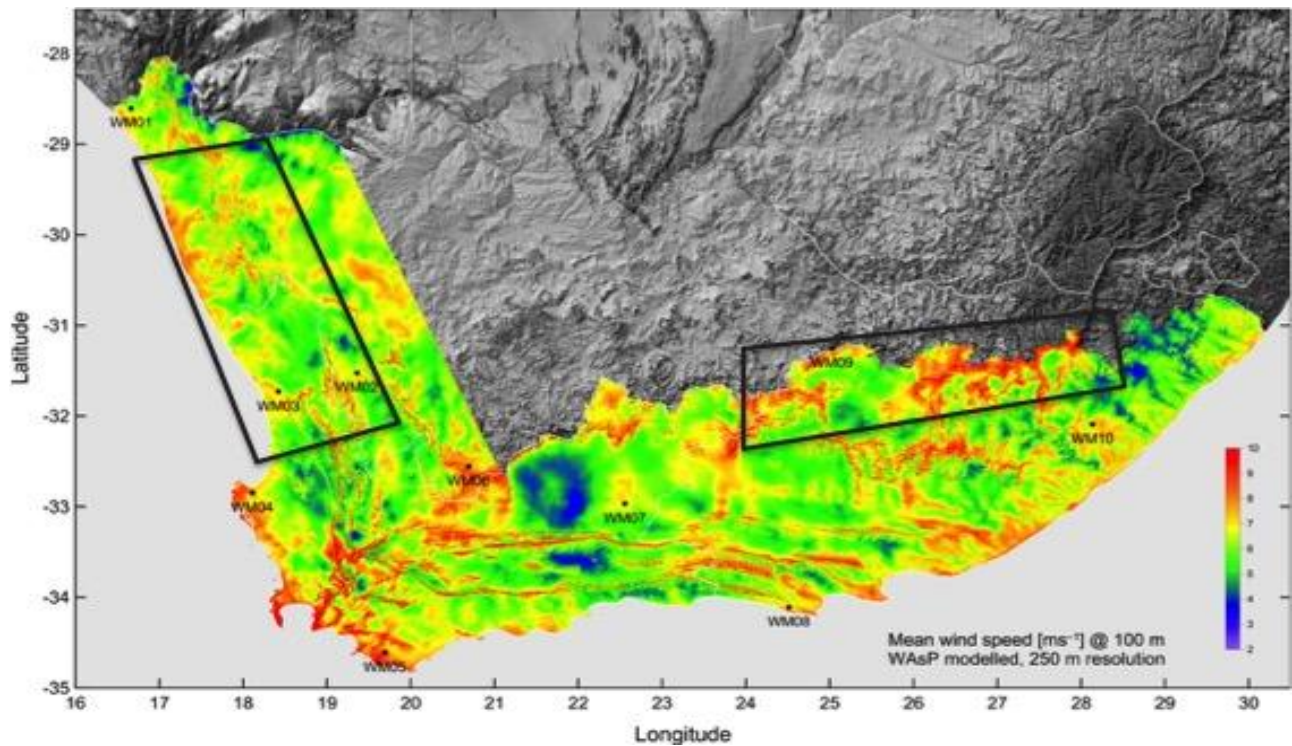


Figure 2.16: Wind resource quality in South Africa

(Source: WASA, 2014)

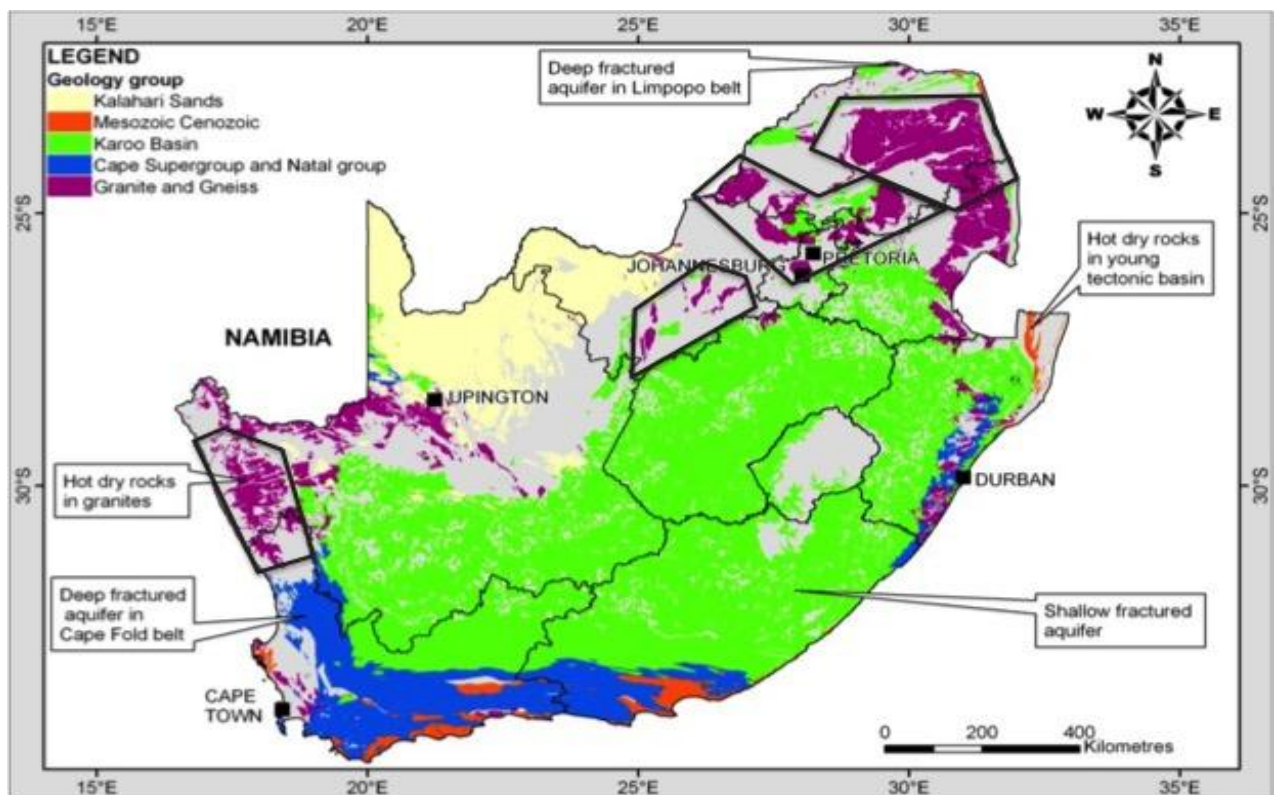


Figure 2.17: Geological map of South Africa

(Source: Tshibalo et al., 2015.)

- Geothermal

For the data of this chapter, only the ‘hot dry rock’ method was considered because it has the highest potential for electricity generation and future development (IRENA, 2014c; GEA, 2013). No experience with mining operations could be identified (see Table 2.1). Figure 2.17 indicates the mining locations with the highest potential. In granite areas, 3 000 m to 5 000 m have to be drilled. The service infrastructure is limited, as no larger projects exist in the country. Projects can be realised on a small to utility scale (Tshibalo et al., 2015).

- Biomass

The data for electricity generation with biomass focuses on the matured technologies, including direct combustion in stoker boilers, low-percentage co-firing, anaerobic digestion, municipal solid waste incineration, landfill gas, and combined heat and power (IRENA, 2015a). No experience with biomass electricity generation at mining operation could be identified globally (see Table 2.1). As can be seen in Figure 2.18, South Africa is a water-scarce country, which makes fuel availability medium with some potential in the north-east area. The service infrastructure is still a challenge, which lowers the reliability of the system and fuel supply (Van Zyl, 2010; Bole-Rentel and Bruinsma, 2013; IRENA, 2012).

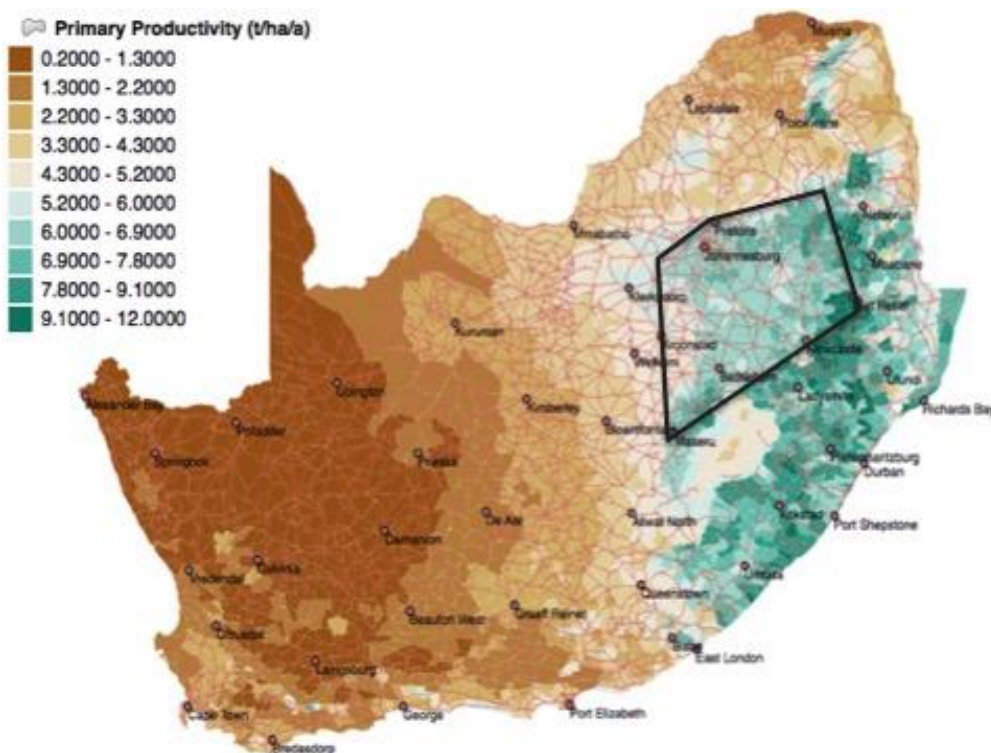


Figure 2.18: Net primary productivity of the land
(Source: Schulze, 2007)

- Battery storage

The data for lithium-ion and lead-acid is presented, as cost and performance levels are improving, especially in comparison to sodium-sulphur batteries (IRENA, 2015b). Batteries can extend the capacity factors of non-baseload technologies, like solar PV and wind power (Dickens et al., 2014). The global experience is limited with one operational project in Australia (see Table 2.1). The service infrastructure is still limited. Two operational projects were identified with 10 kW and 20 kW (DOE, 2015b; IRENA, 2015b).

- Hydro power

The data represented for hydro power excludes pumped storage. At present, one project in Chile represents limited experience with mining (see Table 2.1). Figure 2.19 shows that power source availability, especially for micro projects, is moderate in south-eastern regions of South Africa. The service infrastructure is improving as more projects are being introduced, but it is still in its infancy. It is possible to realise projects on a small- to utility scale (Klunne, 2012; Rycroft, 2014a). However, on-site executions are highly constrained as the mining operation has to be close to the hydro facility.

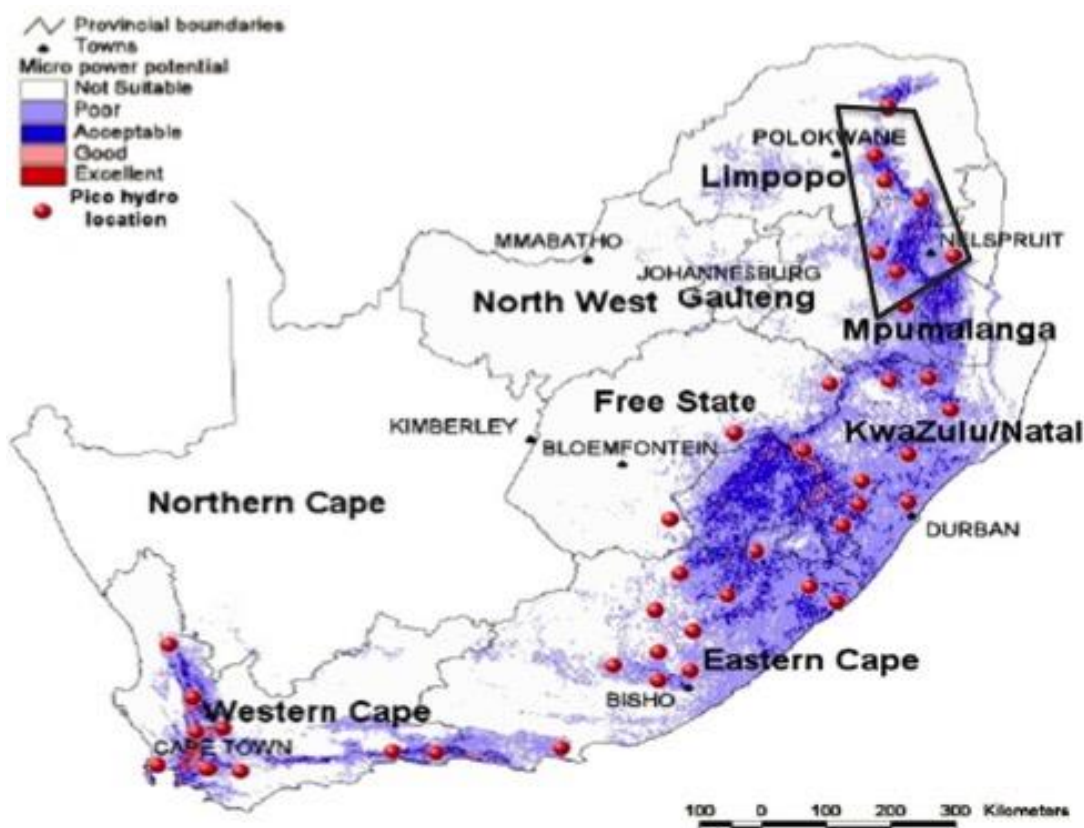


Figure 2.19: Hydro power potential
(Source: Kusakana, 2014)

2.4 Business models

To be able to find the most attractive business model, influencing factors have to be investigated and evaluated. A country's or province's legislative and regulatory framework builds the foundation for the selection of a business model (Fitzroy et al., 2012). This section focuses on business models of renewable energy projects at mining operations, as initial expenses could be higher and the experience with present sources is well established. Table 2.3 provides a summary of the main organisations and the regulatory and policy framework for renewable energy in South Africa. In South Africa, the government is presently not supporting the implementation of off-grid industrial electricity generation from renewable sources. However, there are plans to implement subsidies until 2020 for solar photovoltaic electricity generation (Ahlfeldt, 2013).

Table 2.3: Governmental and regulatory structure for renewable energy in South Africa

Organization	Purpose	
Department of Energy (DoE)	The governmental body in South Africa that is responsible for creating policies and strategies regarding energy production and administration.	
Department of Environmental Affairs (DEA)	The governmental body to ensure the protection of the environment and conservation of natural resources, in balance with a sustainable development of the country.	
Energy Development Corporation (EDC)	Governmental agency to support the development of renewable energy and alternative fuels through investment.	
National Energy Regulator of South Africa (NERSA)	Regulating authority that supervises over the electricity supply industry.	
Policy	Purpose	Introduction
White Paper on Energy Policy	General energy policy. Set goal of developing renewable energy by reforming fiscal, legislative and regulatory regimes.	1998, renewed 2009
White Paper on Renewable Energy	Laid the foundation for the widespread implementation of renewable energy, and set target of 10 000 GWh by 2013.	2003
National Cleaner Production Strategy	Framework (non-binding) to promote sustainable energy production and consumption across South African industries.	2004
Energy Act	Contained strategy for increased generation and consumption planning (renewable and conventional energy sources).	2009
Renewable-Energy-Feed-in-Tariff-program (REFIT)	Set tariffs for wind, small hydro, concentrated solar, and landfill gas technologies. The tariffs were aligned with falling technology costs in 2011.	2009
Integrated Resource Plan (IRP)	A national, long-term plan on electricity supply, based on nuclear power, coal and renewables. Total PV capacity goal is 8,400 MW. The REIPPP falls under this plan.	2010–2030
Renewable Energy Bids (REBID)	Independent power producers bid for on-grid production capacity. In the first round (2012), 1,415 MW was allocated across concentrated Solar PV, Concentrated Solar PV, and biogas.	2011
Source: Boyse, Causevic, Duwe and Orthofer, 2014; DoE, 2015a; DEA, 2015.		

This section discusses the attractiveness of the different business models for South African mining corporations to execute renewable energy projects. Business models entailing wheeling agreements with Eskom were not considered, as costs can add up to 18% to the kWh price and the levelized costs of renewables are very close to Eskom's (Rycroft, 2014b; Haw, 2013). The following 4 models are investigated with the assistance of the references of Boyse et al. (2014); GIZ (2014); Banerjee et al. (2015):

- Self-generation model

In the case of the self-generation model, the mining corporation develops a renewable generation source to reduce electricity costs and to increase independence. Grid-connected mines use this model as a separate electricity source, which is only connected to the mine. To save costs and transmission losses, the plant should be as close as possible to the mining operation. It is possible to implement this model in two ways. The first is for the mine to develop, finance and operate the plant on its own land, using a sub-contractor for the development. The second is to lease its own land to an independent power producer (IPP), who then sells the electricity to the mine. An example is provided in section 2.2.4 with the Cronimet Chrome Mine.

The benefit of the self-generation model is that the smallest number of actors is involved and, therefore, this model is presently preferred by experts. The disadvantage is the high initial investment cost – which represents a shift from operating expenses (diesel fuel or Eskom electricity costs) to capital expenses (plant costs). Thus, this model is only rewarding in the long term. The risk for an independent power producer is the long-term commitment to only one client, the mine. Factors like changing commodity prices or operational expenses can lead, in the worst case scenario, to the closure of a mine (Jamasmie, 2014).

- Industrial pooling model

The industrial pooling model entails several corporations with mining operations situated close to one another forming a partnership to reduce electricity generation costs. The foundation of this model is the building of a consortium to enter a long-term power purchase agreement with shared renewable energy assets. As in previous models, the project can be realised by using combined financial investments and a sub-contractor to build the plant. The plant would be situated on the land of one of the

mining operations. Another option is to use an IPP, and then use a mini-grid to distribute the electricity.

According to Table 2.1, the only project of this type could be found in Lac de Gras, northwest in Canada. Two mining corporations, Rio Tinto and Dominion Diamond, created a joint venture to realize a 9,2 MW hybrid wind/diesel off-grid plant to power their operations. The wind project costs amounted to €28,2 Million with a predicted payback time of 8 years, resulting from the diesel savings (Rio Tinto, 2015).

The advantage would be a lowering of the electricity costs as a result of a higher economy of scale than in the case of self-generation. The difficulty, however, lies in the planning process of the model. Experience has shown that a joint capital investment of competitors is difficult to achieve, owing to different interests, diverse lifespans of the mines, and a lack of knowledge about renewables.

- Net metering model

The net metering model can only be implemented by grid-connected mines, which purchase electricity from the national supplier. The purpose of this model is to lower long-term electricity expenses, avoid potential electricity interruptions and lower CO₂ emissions. This model can be installed by the mine itself, using a sub-contractor, or by an IPP. Eskom, the organisation operating the national electricity grid purchases the excess electricity produced by the renewable source. For clarification purpose, wheeling would be the process of using Eskom's grid to transmit the electricity produced from the plant to the point of usage, which is based on a fee for each unit transmitted.

The benefit of the system is to gain additional revenue for the operator of the system. In addition, no electricity is wasted as all energy generated is used. The disadvantage of the model is that net metering is currently not supported by the regulatory framework in South Africa and is, therefore, not feasible.

- Self-generation model for powering rural settlements

The self-generation model for powering rural settlements is especially for off-grid mines running on diesel generators. In this case, a rural settlement would be situated close to the mine. The community could be connected via a mini-grid through an own

investment or an IPP. The outcome would be the reduction of electricity expenses for the mining corporation and rural electrification. The renewable electricity plant can be installed via a sub-contractor, by the mine itself, or through an IPP. The neighbouring community would apply for government support to run a transmission line.

The advantage of the model is that selling the unused electricity to the community creates extra revenue. Therefore, the mine could contribute to one of the government's targets of electrification for all. A difficulty presented by the model is the deviation of active mines from their core business. In addition, the process of obtaining required permits from Eskom, NERSA and environment or land management offices is lengthy and difficult. Furthermore, the fact that the mine provides electricity to the public would necessitate a generation license, especially if the settlement is already connected to the Eskom grid. The regulatory difficulties in South Africa make this model unfeasible.

Anglo American Platinum and Canada based Ballard Power Systems passed the regulatory difficulties and started in the beginning of 2015, a 12 months trial run, by electrifying 34 households in the Free State, South Africa. The settlement is not connected to the national Eskom grid and is now powered using a methanol fuel cell prototype product. The system includes a battery bank and inverter operating within a micro-grid and is designed to provide a total of 15kW of fuel cell-generated electric power, and can generate peak power of 60 kW with the support of batteries (Kotze, 2014).

The essence of this section was to investigate the most attractive business model to realize renewable energy projects at mining operations in South Africa. The model of self-generation was selected as most attractive and will be used as one of the pillars to create the model in chapter 5.

2.5 Corporate development

Business and private consumer awareness of environmental issues has risen dramatically over the past two decades. Possible results are public reporting and increased electricity prices through taxes or levies (Cummins et al., 2008). Members of the Energy Intensive User Group of Southern Africa, of which 47% are mining corporations, have become aware of this development and have started to make their efforts to become "greener" public on their webpages and other media channels. Most efforts are projects to reduce

their carbon footprint. Indeed, financial advantages still have the highest priority, such as the low running costs of the technology and carbon taxing (EIUG, 2014b).

Table 2.4 shows that the vast majority – 25 out of 31 – of EIUG members give detailed information on their environmental protective programmes, primarily energy efficiency initiatives, on their webpages. Three of the companies provide the information that they are in the process of conducting feasibility studies on photovoltaic and wind power and one has built a 1 MW PV solar plant.

Table 2.4: Energy efficiency programmes of EIUG members

Company name	Reference	Energy efficiency / Environment protection	Renewable energy
AECI	(AECI, 2011)	Yes	No
Air Liquide	(Air Liquide, 2014)	Yes	No
Anglo Operations	(Anglo Operations, 2014)	Yes	No
Anglo Platinum	(Anglo Platinum, 2014)	Yes	Yes (PV feasibility)
AngloGold Ashanti	(AngloGold Ashanti, 2014)	Yes	No
ArcelorMittal	(ArcelorMittal, 2014)	Yes	No
Assore	(Assore, 2014)	Yes	No
BHP Billiton	(BHP Billiton, 2014)	Yes	No
Columbus Stainless	(Columbus Stainless, 2014)	Yes	No
Consol Glass	(Consol, 2014)	Yes	No
Evraz Highveld Steel	(Evraz, 2014)	No	No
Exxaro Resources	(Exxaro, 2014)	Yes	Yes (wind and PV feasibility)
GFI Mining South Africa	(Gold Fields, 2014)	Yes	No
Glencore	(Glencore, 2014)	Yes	No
Harmony Gold Mine Company	(Harmony Gold, 2014)	Yes	No
Implats	(Implats, 2014)	Yes	No
Kumba Iron Ore [64]	(Anglo Operations, 2014)	Yes	No
Lonmin	(Lonmin, 2014)	Yes	Yes (wind feasibility & 1 MW PV)
Mondi	(Mondi Group, 2014)	Yes	No
PPC Cement	(PPC Cement, 2014)	Yes	No
Rand Water	(Rand Water, 2014)	No	No
Richards Bay Minerals	(Richards Bay Minerals, 2014)	Yes	No
SA Calcium Carbide	(SA Calcium Carbide, 2014)	No	No
SABMiller	(SABMiller, 2014)	Yes	No
Samancor	(Samancor, 2014)	No	No
SAPPI South Africa	(Sappi South Africa, 2014)	Yes	No
Sasol	(Sasol, 2014)	Yes	No
Scaw Metals Group	(Scaw, 2014)	Yes	No
Sublime Technologies	(Sublime, 2014)	No	No
Transnet	(Transnet, 2014)	No	No

2.6 Environmental factors

The Organization for Economic Cooperation and Development (OECD) predicts, in its Environmental Outlook, that global greenhouse gas emissions will increase by 37% between 2008 and 2030. The highest contribution to emissions is made by the BRICS nations (OECD, 2008). In 2002, on the African continent, 90,6% of CO₂ was emitted by South Africa (United Nations, 2005). The main sources of air pollution in South Africa are heavy industries via activities such as electricity generation, mining and smelting operations (Southern African Development Community, SADC, 2012).

The South African government has subsequently announced its intention to launch a carbon emissions tax (Republic of South Africa, 2013). The bill is part of the commitment to reduce greenhouse gas emissions to below business as usual by 34% by 2020 and 42% by 2025. The tax is planned to be introduced at a marginal rate of €8,61 (ZAR120) per ton of CO₂. Taking into account the listed tax-free threshold, the effective carbon tax rate will vary between €0,43 (ZAR6) and €3,44 (ZAR48) per ton of CO₂. All calculations are closely linked to the Department of Environmental Affairs' mandatory reporting requirements. Entities will be liable for: fossil fuel combustion emissions; industrial processes and product use emission; fugitive emissions (National Treasury of South Africa, 2015; Swart, 2015).

According to the latest publication on the 2nd of November 2015 from the national treasury of South Africa, the Draft Carbon Tax Bill includes the following features (National Treasury of South Africa, 2015):

1. Basic 60 per cent tax-free threshold during the first phase of the carbon tax, from implementation date up to the year 2020;
2. Additional 10 per cent per cent tax-free allowance for process emissions;
3. Additional tax-free allowance for trade exposed sectors of up to 10 per cent;
4. Recognition for early actions and/or efforts to reduce emissions that beat the industry average in the form of a tax-free allowance of up to 5 per cent;
5. A carbon offsets tax-free allowance of 5 to 10 per cent;
6. To recognize the role of carbon budgets, an additional 5 per cent tax-free allowance for companies participating in phase 1 (up to the year 2020) of the carbon budgeting system;
7. The combined effect of all of the above tax-free thresholds will be capped at 95 per

cent.

However, there is still a lot of controversy in politics and media about the actual design of the tax, date of implementation and if it will actually be implemented. A scenario analysis by R. Baxter, CEO of the Chamber of Mines of South Africa (2015) states two case scenarios of how the tax would affect two deep underground gold mines close to Johannesburg, owned by AngloGoldAshanti and SibanyeGold (see Addendum G). The Sibanye case predicts a further 30% price increase from 2014 to 2017. The Anglo case forecasts its electricity tariff to increase from €4,30 (ZAR60) cents / kWh in 2013 to €10,9 (ZAR152) cents / kWh in 2020, without the tax an increase to €10,4 (ZAR145) cents / kWh is projected.

The treasury claims that the tax will not affect the cost of electricity by Eskom, as the national supplier might be excluded or the existing environmental levy included in tariffs will be replaced by the tax. In addition, plans are still uncertain about a levy reduction and other “revenue recycling” measures, which will be specifically aimed at not increasing costs in distressed sectors such as mining (Van Rensburg, 2015; Peyper, 2015; Dhawan, 2015; Seccombe, 2015).

The electricity generation in South Africa is responsible for 48% of the country's carbon emissions. The extra costs of the emission tax on generating electricity will, in all likelihood, be passed on to the consumer. The increased electricity price could have a severe impact on the competitiveness of intensive electricity users in South Africa. The aim is to reach a CO₂ plateau in 2025, to prevent possible trade restrictions with first world countries, due to their likely future regulative framework (Mammatt et al., 2011; Alton et al., 2014).

2.7 Core information for the following research

This section provides an overview in Table 2.5 on the information gathered in this chapter, which was directed to answer the research objectives stated in Figure 2.1 in section 2.1. The results will be used as the foundation and decision framework for the research process in chapter 4 and 5.

Table 2.5: Overview of results of chapter 2

Topic	Result
Renewables sources with potential	<ol style="list-style-type: none"> 1. Solar PV 2. On-shore wind 3. Geothermal
Possible electricity sources	<ul style="list-style-type: none"> • Diesel generator • Hybrid diesel generator/solar PV • Hybrid diesel generator/on-shore wind power • Hybrid diesel generator/geothermal power • Eskom grid connected • Hybrid Eskom grid connected/solar PV • Hybrid Eskom grid connected/on-shore wind power • Hybrid Eskom grid connected/geothermal power
Business model	Self - generation
CO ₂ tax	€0,00 (ZAR0) - €3,44 (ZAR48)

2.8 Conclusion

The purpose of this chapter was to determine the influences that shape the market potential of renewable sources of electricity at mining operations in South Africa. The results reveal that the most lucrative renewable electricity sources for mining corporations operating in South Africa, in descending order of suitability, are solar PV, on-shore wind and geothermal technology.

Owing to the electricity usage patterns of mining operations and the intermittency, especially of solar PV and wind, a hybrid version with current sources has to be used. To execute a project, the business model of self-generation was identified as the most promising, and can be realised through own investment or an IPP agreement.

The past and projected future economic situation of mining corporations operating in South Africa creates the opportunity for renewable electricity sources to contribute to their long-term success. The advantages would be greater independence from diesel and Eskom's electricity supply, lower electricity costs and reduced CO₂ emissions. However, considering the shift from operational to capital expenses, some key challenges exist: firstly, the need to foster greater trust in investors so that PPA projects may be realised, and secondly and of greater importance, the need to encourage further research for

decision-making leaders of mining corporations with regard to a possible fit of renewable electricity sources to the specific requirements of mining operations (Judd, 2014b).

The following chapters conducted further research to contribute to this development. The chapter investigates research approaches to include the perspective of mines in order to contribute to this analysis as best as possible.

Chapter 3 Selection and assessment of possible research approaches: A review

3.1 Introduction

The purpose of this chapter is to assess possible research approaches and select the most valuable one to combine the internal and external factors for analysing a possible fit of renewables to mining operations in South Africa. Previous research has been directed mainly at analysing the external influences for renewable sources relating to mining operations in South Africa (see section 1.4.1). The contribution of this chapter is to identify a research approach, which incorporates the internal business approach of mining corporations to evaluate electricity sources. The approach is used to structure the research, as the existing theory and previous applications create a greater research foundation through experience and further ensure that all aspects are considered to achieve the research objectives. The selected approach of this chapter represents the foundation to ultimately combine the internal evaluation process of mining corporations with the current knowledge about the external framework.

The aim of this chapter is to create a solid foundation by selecting an appropriate research approach and to examine how past applications can contribute to this research. The objectives are illustrated in Figure 3.1. Chapter 5 implements the selected research approach, from a mining perspective, with the final result of a clear evaluation and comparison of how renewable and current sources perform for mining corporations in South Africa.

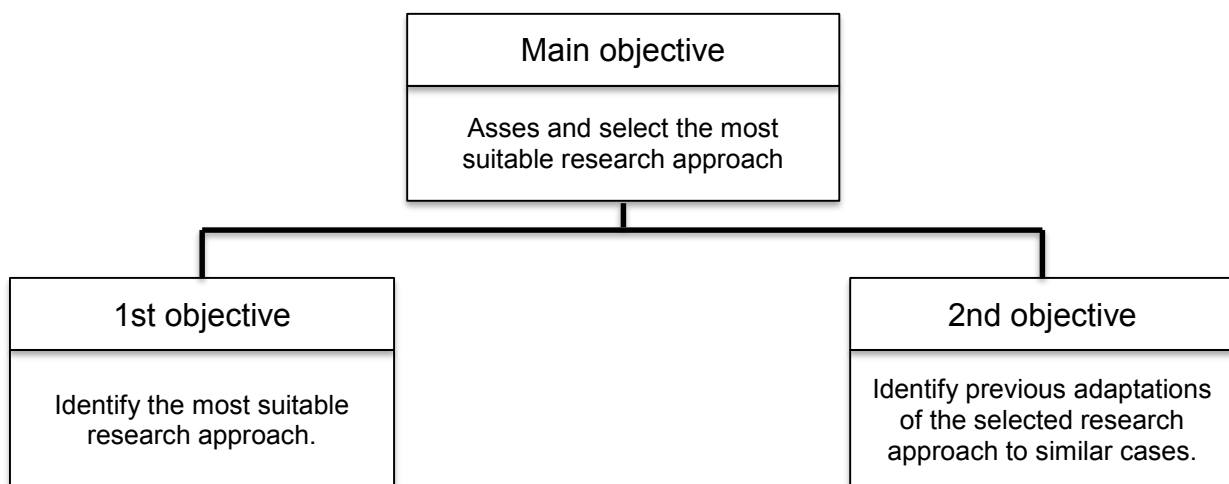


Figure 3.1: Research objectives

3.2 Method selection

3.2.1 Requirements of the method

For the purpose of this study, the researcher decided to use a substantiated research method. Extensive academic research has already been done to ensure that the methods considers all aspects regarding its overall purpose. Therefore, it provides more assurance in respect of this research that all aspects are investigated. Secondly, previous applications in similar cases contribute to more understanding of how the objectives can be met. For instance, the research method was used from a different decision-maker's perspective to analyse electricity sources, like a governmental body.

This section describes the requirements of the research method to best address the main research objective of this chapter, namely to investigate the business approach of mining corporations to evaluate and select electricity sources. In the past, almost no evaluation was necessary, as Eskom, or in remote locations, diesel generators were used. The development of technologies like renewables increased the importance of the evaluation approach. The requirements were determined throughout the research process and especially with the input of experts from the mining and energy industry (see Addendum A). This was conducted with the help of the decision framework defined in chapter 2, an overview was provided in section 2.7. They were to be used to find the most appropriate basis for research to investigate this decision framework. To be able to achieve a successful investigation of the main objective, the research method needed to fulfil the following requirements:

1. To provide information to mining corporations about a possible fit of renewable energy in the context of their own unique usage patterns (Section 2.2). As described in the introduction, recent developments have increased the attractiveness of renewable energy. Consequently, research has to be conducted to illustrate to mining corporations how this could fit their specific needs.
2. To add to the education of renewable energy companies about the needs and business structure of this new type of customer, namely mining corporations. The approach has to create a greater understanding of renewable energy companies and how best to customise the information about electricity sources to the specifications of mining operations.
3. To investigate the strengths and weaknesses of selected electricity sources. The approach has to be able to contribute to the reasoning why a selected electricity source

has or has not been appropriate for mining operations. The weaknesses should illustrate what potentially has to change to make it more attractive.

4. To compare different selected electricity sources according to the specific needs of mining operations. It should be possible to illustrate why certain sources have provided a better fit for mining operations than others. The comparison between presently used and new technologies adds to a better understanding.

3.2.2 Possible methods

This section lists different popular methods, which could possibly assist to structure the research. All methods listed in Table 3.1 were considered and investigated. The MCDA, the balanced scorecard (BSC) and strategic planning methods were found to be most likely to contribute to the characteristics listed in section 3.2.1. The other methods that are used less frequently are scenario and contingency planning (Ringland, 2006), change management programmes (Cameron and Green, 2012), the value chain (Presutti and Mawhinney, 2013), Porter's Five Forces (Hough et al., 2011), SWOT analysis (Hough et al., 2011), core competencies and capabilities (Tidd, 2006), strategic benchmarking (Watson, 2007), PESTLE analysis (Grant and Jordan, 2012) and cost-benefit analysis (De Rus, 2010). Table 3.1 gives the different methods and illustrates which requirements the three selected methods fulfilled. The numbers in the top row are linked to the requirements in section 3.2.1.

Table 3.1: Possible strategic methods

Method	Requirement 1	Requirement 2	Requirement 3	Requirement 4
Multi-criteria decision analysis ¹	✓	✓	✓	✓
Balanced scorecard ²	✓	✗	✓	✗
Strategic planning ³	✓	✓	✗	✗
(1) Ishizaka and Nemery, 2013; (2) Westermann and Sehl, 2006; (3) King and Cleland, 1987				

Each of the three selected methods is briefly introduced, a possible utilisation is described and a contribution according to these characteristics is discussed:

- A strategic planning (SP) model is a tool for businesses to organise their current operations to realise the desired future. The model can be seen as a road map for the business to get from the current situation to future goals. It is of importance for businesses to create a plan, as it provides clarity on how to achieve the planned goals.

It can be seen as a manual on how to consider factors in the external and internal environment and how to generate the best possible outcome (King and Cleland, 1987). Every strategic planning model should entail seven elements, namely plan-to-plan (rarely used); mission; needs assessment; strategic objectives; outcome measures; strategies and performance feed-forward (De Beer, 2000).

The SP approach can be adapted and implemented according to the main research objective of this chapter. A mining corporation should express in its strategic mission statement the aim to diversify its electricity mix and should specifically set out its approach to adopting renewable sources (Cetindamar et al., 2013). The SP process would first identify the exact objectives are to be achieved. According to the objectives, the possible electricity-generating technologies would then be introduced, followed by the identification of the internal and external issues and requirements, which have to be fulfilled. Lastly, the SP approach could investigate which technology would be best suited, according to the internal and external influences identified.

A shortcoming of the SP approach is that it will not identify strengths and weaknesses, nor will it compare the selected technologies according to the specific demand requirements of mining corporations. Furthermore, it will be influenced strongly by the mining corporations' strategic aims. Another shortcoming – relevant to this paper – is the more strategic nature of the SP to improve a company's business coordination (Jakhotiya, 2013). The objective of this research is oriented towards a once-off decision.

- The balanced scorecard (BSC) is a tool that converts the strategy and mission of an organisation into performance indicators that are of a qualitative and quantitative nature. The indicators provide the structure for an effective, dynamic and timely strategic management and measurement system to achieve the overall strategy (Westermann and Sehl, 2006). The scorecard approach identifies elements and requirements that have to be considered in order to follow the strategy with the best possible outcome. The original Balanced Scorecard of Robert Kaplan and David Norton (1992) entails four scoring elements, namely financial, customer, internal business processes, and learning and growth (Linard and Yoon, 2000).

The BSC principle could have been used to fulfil the main research objective of this chapter, with some adaptation for mining corporations that have the goal of getting involved in renewable energy sources. The adaptation and application would contribute to providing information to mining corporations, as it would show all the criteria that a mining corporation has to fulfil to realise such a project. The adaptation would replace the original scoring elements with more energy-related ones, for instance, financial, environmental, strategic and operational. The corporation could measure its own standards against the ones from the renewable energy source and see where it has to improve or where issues could arise. After adapting and applying the scorecard to evaluate the selected technologies, comparisons could then have been made according to the requirements.

The BSC approach would contribute to informing mining corporations about renewable energy, by illustrating the main requirements that have to be fulfilled when realising on-site renewable energy projects. The mining corporation would then understand in which areas adjustments have to be made or, perhaps, that no realisation of objectives would be possible as requirements simply are not achievable.

The shortcoming here is that the requirements are not based on the specific needs of a mining corporation. Furthermore, the fact that the requirements are based on what the technology can supply, rather than on the demands of the mining corporation, makes comparisons difficult, as the requirements might differ.

Another problem is that the BSC approach requires the mining corporations to have the initial strategic goal to get involved in renewable energy (Person, 2013). As the market is still relatively new, mining corporations first have to be informed about the possibilities of renewable energy in catering for their specific needs (Chislett, 2014). Consequently, with adapting and applying the BSC, the criteria used are based on the technology's specification and not from the mining corporations' perspective, which limits the informative data. The approach should not illustrate the requirements to realise the technology, but rather how it would work based on the mining corporations' needs.

- The multi-criteria decision analysis (MCDA) is a method that is utilised in making complex decisions. When making complicated decisions, it is necessary for the

decision-makers to handle a large number of criteria, which influence the decision. The MCDA method supports the decision-makers in the selection of the best possible alternative (Ishizaka and Nemery, 2013). The MCDA process is generally divided into three main steps, namely the problem structuring, the model building, and the approval of the model (Stewart and Belton, 2002). The problem-structuring phase comprises, firstly, the investigation of possible alternatives; secondly, the identification of criteria that influence the decision; thirdly, the investigation of uncertainty in the process; and, lastly, the examination of influences from the external environment. The model-building phase represents the development of a method to evaluate the alternatives according to the criteria while the approval phase tests how accurately the model is working (Mateo, 2012).

It was found that the MCDA method could be adapted to the context of the main research objective of this chapter as it could illustrate to mining corporations which selection of electricity sources would be most suitable. The method would achieve this by utilising the mining corporations' own evaluation criteria. Firstly, the research would identify the criteria that mining corporations use to evaluate possible electricity sources. Secondly, the type of electricity source and possible uncertainties in the internal and external environment would be identified. Thirdly, based on the identified criteria, an MCDA method would have to be developed to analyse different electricity-generating technologies. The most likely and attractive technologies could then be analysed and evaluated.

The MCDA method developed for the purpose of this research would provide information to mining corporations by indicating the possible fit of renewable energy. The corporations would be able to understand, according to their own evaluation criteria, what it entails to use renewable energy. However, the method would be developed according to a specific type of electricity source to ensure that the same criteria can be used – which would limit the applicability to technologies. Possible types of technologies are self-generating sources like diesel generators and trigeneration systems like combined heat and power (CHP).

The renewable energy company would gain more understanding of how mining corporations evaluate such projects. Consequently, it would ease the communication

about a possible project realisation, as information packages about the technology can be customised from the beginning.

The method enables the mining corporation to identify the strengths and weaknesses of the selected technologies from their own point of view (Stewart and Belton, 2002). A clearer understanding of how the new technologies would perform compared to the present ones would be obtained. It would also be possible to compare, according to each criterion, how the different alternatives perform while paying close attention to external influences.

3.2.3 Selection of strategic method

The MCDA technique was selected as the most appropriate method to investigate the main research objective of this chapter. The technique evaluates and analyses electricity options from the perspective of mining corporations. The other two approaches would require the initial aim of the mining corporations to be to implement renewable energy and would not analyse the technologies according to the mines' own criteria. As the market for renewable sources of electricity is still in its infancy (Chislett, 2014), the MCDA method was considered more suitable.

The renewable energy company would be able to gain the most valuable information from the MCDA method, as it identifies the criteria and structure that are important to mining corporations. In addition, as the technology is new for mining corporations and not for the renewable energy company, it would be more beneficial to analyse the strengths and weaknesses and to compare the technologies from the perspective of the mining corporations.

Another reason is that both SP and BSC are more oriented towards the successful realisation of a business strategy, than a physical project. The BSC aims continually to measure, according to selected criteria, how close the performance is to the overall strategic goal. The research content of this chapter, however, aims for a once-off decision.

Lastly, the SP approach involves the investigation of the different technologies, the internal issues, the external influences, the market potential and a possible scenario analysis. As the market is still in its infancy, the key focus should be on the education of the mining corporations.

3.3 MCDA method selection

3.3.1 Requirements of the MCDA method

The theory of MCDA consists of different methods, which have to be carefully chosen with regard to the context of adaptation. This section describes the requirements of the MCDA method to best address the main research objective of this study, namely to investigate a possible fit for how renewables can perform in respect to the specific characteristics of mining operations in South Africa. The required elements were used to scan different MCDA categories and methods to identify the one best-suited for adaptation in the context of this study. It is important to mention that it was often difficult for the researcher to justify the selection of a method. None of them are perfect, nor is it possible to apply them to all decision problems. Each method entails its own limitations, characteristics, principles and perspectives (Ishizaka and Nemery, 2013). Consequently, the following requirements were used to make the best possible selection:





1. Once-off decision – Specialist knowledge of the characteristics of the MCDA method is required in order to contribute successfully to this type of decision. The decision to select the best-suited electricity source has to be made once and is not recurring. Only after years of usage a re-evaluation may be necessary as price structures or performance levels may have changed (Khatib, 2008).
2. Investigate the evaluation structure – The implementation of the MCDA method has to bring about a clear understanding of the internal evaluation structure of mining corporations. It has to show how each criterion contributes to the overall decision. This may lead to renewable energy companies having a better understanding of a potential new type of customer, namely mining corporations.
3. Analyse alternatives separately – The method has to deliver the basis for a separate analysis of each alternative. It should make it possible to illustrate and explain the strengths and weaknesses of an alternative independently of the other alternatives. The decision-maker has to understand the implications of selecting a certain option.
4. Compare alternatives – It has to be possible to compare alternatives according to their strengths and weaknesses. The results should demonstrate the advantages and disadvantages of selecting one electricity source above the others. The results ought to provide the decision-maker with the necessary information in order to optimise his or her selection.

5. Incorporate unknown alternatives – As the concept of renewable electricity sources is relatively new for mining corporations in South Africa (Boyse et al., 2014), the method has to be able to incorporate the analysis of alternatives not known to the decision-maker. The basis for the adapted method, before implementing the data of alternatives, should not include any predispositions towards a specific outcome.

3.3.2 Possible MCDA methods

The purpose of this section was to select the MCDA method, which is best suited to contribute to the achievement of the research objectives. This was achieved by investigating the categories and methods according to the requirements listed in section 3.3.1 (see Table 3.2). For structural purposes, the reasoning was sub-divided into the selection of the most appropriate MCDA category, and then the method.

Table 3.2: Selection process of MCDA method

MCDA categories	Req. 1.	Req. 2.	Req. 3.	Req. 4.	Req. 5.
Goal, aspiration or reference level methods	✗	✗	✗	✗	✗
Outranking methods	✓	✓	✗	✓	✓
Value measurement methods	✓	✓	✓	✓	✓
<div style="text-align: center;">  <i>Selection</i>  </div>					
Value measurement methods					
Measuring attractiveness by a categorical based evaluation technique method (MACBETH)	✓	✓	✗	✓	✓
Analytical hierarchy process (AHP)	✓	✓	✗	✓	✓
Multi-attribute value theory (MAVT)	✓	✓	✓	✓	✓
<div style="text-align: center;">  <i>Final choice</i>  </div>					
Multi-attribute value theory					

3.3.2.1 Selection of MCDA category

It is generally accepted that MCDA methods can be divided into three broad MCDA categories, or schools of thought, namely the value measurement methods, the goal, aspiration or reference level methods and outranking methods (Stewart and Belton, 2002). The list below, firstly, introduces the theory of each category, followed by the examination of which requirements are or are not satisfied. Lastly, the category is selected and reasons are stated.

- Goal, aspiration or reference methods – These methods establish, in coordination with the decision-makers, desirable or satisfactory levels of achievement for each evaluation criterion. The results of the implementation identify the alternative that is closest to realising these goals and aspirations (Roy and McCord, 1996). The method is preferably used for decisions on problems of a repetitive nature or familiar to the decision-maker (Stewart and Belton, 2002). This contradicts requirement 1 and 5. In addition, the methods necessitate that performance measures are available in quantitative form (Chang, 2011). This eliminates requirements 2, 3, and 4, given that the selected criteria for this study are qualitative in nature.
- Outranking methods – These methods compare alternative courses of action in a pairwise approach. This is initially done on a criterion-by-criterion basis in order to state the preference of one over the other. Thereafter, the methods aggregate such preferences of all selected criteria in order to identify the level of evidence favouring one alternative over the others. Partial and complete rankings are constructed (Geldermann and Schöbel, 2011). Consequently, the methods investigate the internal evaluation structure and compare alternatives that are new or known to the decision maker, which fulfils requirements 2, 3 and 4. Requirement 3 is not achieved, as pairwise comparisons are used, which makes it impossible to analyse alternatives separately. The methods are used for discrete choice problems (Bouyssou et al., 2002), which satisfies requirement 1.
- Value measurement methods – The methods create numerical scores for each alternative analysed to illustrate the preferences associated with each alternative. Initially, scores are established for each selected criterion separately. Thereafter scores are synthesised on the basis of relative importance. This, in turn, effects aggregation into higher-level preference methods – which enables the drawing up of a complete ranking with scores. The basis of the methods differs as some are built on pairwise comparisons and others on preference functions (Keeney, 1992). The foundation of constructing preference functions for each criterion fulfils requirements 2 and 3. As the decision-maker does not have to formulate any pre-set ambitions, requirement 5 is satisfied. The methods are suited for once-off decision problems, to please requirement 1 (Triantaphyllou, 2000).

For the purpose of this study, the value measurement school of thought was selected, while the outranking methods was a close second. The value measurement methods satisfied all requirements of section 3.3.1. Firstly, the value measurement methods were

better suited than the outranking methods with regard to requirement 2. By creating value functions for each selected criterion and incorporating relative weights, the internal structure of mining corporations to evaluate electricity sources is illustrated in detail. The outranking methods did not satisfy this requirement to the same extent, as criteria were not investigated separately. In addition, the outranking methods were not able to fulfil requirement 3, as the results of the analysis were not separate for each alternative, but appeared in relation to each other. Lastly, the goal, aspiration or reference school of thought could not fulfil any of the requirements.

3.3.2.2 Selection of value measurement method

The selected value measurement school of thought, also known as the 'full aggregation approach', was the most detailed and comprehensive MCDA option (Eliasson and Lee, 2003). Within this school of thought, different methods exist. This section investigates three established method designs, which produce the most detailed results of the value measurement methods (Ishizaka and Nemery, 2013; Linkov and Moberg, 2012). In the following list, the choice of the best-suited method for the adaptation to the context of this research is identified and discussed.

- Measuring attractiveness by the categorical based evaluation technique method (MACBETH) – This method consists of three steps. The first step is to structure the problem, which is followed by constructing a judgement matrix on the basis of interval pairwise comparisons. If consistency of the matrix is proven, the attractiveness can be calculated (Ertay et al., 2013). As the method uses pairwise comparisons, it is difficult to analyse alternatives separately, which contradicts requirement 3. The other requirements can be fulfilled.
- Analytical hierarchy process (AHP) – This method comprises three steps, similar to MACBETH. Firstly, the problem is structured, followed by the creation of a judgement matrix based on ratio pairwise comparisons. Again, if results are consistent, the attractiveness can be calculated. A sensitivity analysis can be conducted to reduce uncertainty (Stein, 2013). As this method also uses pairwise comparison, even though on a ratio scale, requirement 3 is difficult to accomplish. However, all other requirements can be satisfied.
- Multi-attribute value theory (MAVT) – This method entails five steps. The first step is to structure the problem. The second is to determine the criteria that the decision-maker uses to evaluate the decision problem. Thirdly, a scale is developed to measure each

criterion. Fourthly, a value function is created for each criterion. Lastly, the data of each alternative are implemented and results can be analysed and compared. A sensitivity analysis can then be conducted (Stefanopoulos et al., 2014). Since a preference function is constructed for each criterion, alternatives can be analysed separately and in comparison to each other.

The MAVT was selected as it satisfies all requirements of section 3.3.1. The method can be used for once-off decisions (Ferretti et al., 2014). It is the most comprehensive MCDA method and the most detailed way to investigate the internal structure of mining corporations, as a preference function is created for each criterion. The MACBETH and AHP methods are less satisfying on this requirement as each criterion is not treated separately (Ishizaka and Nemery, 2013). Consequently, only the MAVT is able to analyse alternatives separately considering that the results are not based on a pairwise comparison. The three methods enable the decision-maker to choose between unfamiliar alternatives, as no aspirations or goals are required.

3.4 Existing applications to similar cases

3.4.1 Previous MCDA approaches to energy planning

In order to have an overview and an understanding of how MCDA approaches were used in energy planning in recent years, a literature review was conducted. Twenty-six other approaches were identified and summarised in the same way as the MCDA approaches were used, namely according to publication year, energy alternatives selected, final ranking of alternatives, type of criteria used, types of alternatives, main stakeholder (perspective), project size, source of criteria used, and the area of implementation. The results are represented in Table 3.3.

The points below introduce each column in Table 3.3 and provide a brief summary of the findings:

- Column 1 firstly enumerates each article from 1 to 26, with the purpose of using the articles as references in Table 3.4 in section 3.4.2. Secondly, the selection of past MCDA approaches was divided in half: 13 mixed electricity alternatives and 13 purely renewable alternatives. The main reason was to illustrate if there were differences in the selection of the evaluation criteria, which are shown in Table 3.4 in section 3.4.2. Mixed alternatives, besides renewable energy, include other non-renewable energy sources like nuclear, coal and/or fossil fuels.

- Column 2 gives the author and the publication year of the study. Nineteen (73%) of the 26 articles were published between the years of 2009 and 2014, with the oldest in 2001.
- Columns 3 & 4 name all electricity alternatives, which were analysed by the MCDA. Column 4 includes blank rows as not all studies provided a ranking. In the mixed alternatives, i.e. articles 1 to 13, the most frequently nominated alternative was wind with 12, followed by solar (n=11), hydro (n=11), gas (n=11), nuclear (n=10) and coal (n=9). In nine of the 13 articles, rankings and preferred choices were presented. A maximum of the top four choices are indicated. No non-renewable sources made it to the top four approaches. Wind appeared nine times, followed by hydro (n=8) and solar (n=6).

The renewable energy sources (RES), i.e. articles 14 to 26, most recurrently selected wind (n=10) as an alternative, followed by solar (n=9), hydro (n=9) and biomass (n=8). In seven of the 13 articles, rankings and preferred choices were presented. Again a maximum of the top four choices are indicated in Table 3.3. Wind was listed in all seven top ratings, solar in six and hydro in two. Again, the same types of electricity sources, as in the mixed articles, were the preferred choices.

- Column 5 represents the genre of the criteria that the study used to evaluate the alternatives. However, only 16 of the 26 articles clearly sub-divided the criteria into genres. With n=14, technological and environmental genres are used most frequently, followed by economic (n=11), socio-economic/-political (n=6) and social (n=6).
- Column 6, firstly, shows the size of possible projects the MCDA was dealing with. It is divided into small-scale ($0 < x \leq 5MW$) and utility-scale ($x > 5MW$). Secondly, the main stakeholder for the MCDA selection is given. In 19 publications, the purpose was to find the best utility-scale alternative for a country's electricity demand, and in one publication for small-scale residential buildings. No publication for the purpose of a mining operation could be found. The project size was utility-scale in 20 articles and small-scale in one. The other articles did not specify size or main stakeholder.
- Column 7 indicates the types of decision-makers who were involved in identifying the evaluation criteria. In 19 MCDA approaches, decision-makers were not specified and a literature review was used. The other seven approaches used different types of decision-makers depending on the objectives.
- Columns 8 & 9 state the topic of the MCDA approach and the physical area of implementation. Not all studies were specified to countries or areas. A regional

implementation was found in 15 publications. Turkey had the highest implementation rate with five, followed by Spain (n=2) and Greece (n=2). Almost half (n=7) were within the European Union.

Table 3.3: Review of MCDA approaches in energy planning

Article/ Source	Year / References	Energy alternatives	Outcome	Type of criteria	Main		Application topic	Area
					stakeholder /	Decision-makers identify criteria		
1 Mix	2013 / Stein (2013)	Solar (PV); wind; hydro; biomass; geothermal; nuclear; coal; oil; natural gas	1. Solar PV; 2. Wind; 3. Hydro; 4. Geothermal	Financial; technological; environmental; socio- economic/- political	Utility-scale /country	Financial; operational; government; community	A comprehensive multicriteria model to rank electric energy production technologies	
2 Mix	2013 / Boran et al. (2013)	Fossil fuels; geothermal; wind; hydro; natural gas	1. Hydro; 2. Wind; 3. Gas		Utility-scale /country	Not specified / literature review	A multidimensional analysis of electricity- generation options with different scenarios	Turkey
3 Mix	2013 / Ribeiro et al. (2013)	Coal; natural gas; hydro gas; wind; hydro			Utility-scale /country	Electrical engineers; mechanical engineers; environmental engineers	Evaluating future scenarios for the power generation sector using a multi-criteria decision analysis (MCDA) tool	Portugal
4 Mix	2014 / Brand and Missaoui (2014)	Nuclear; coal; solar; wind		Financial; Supply security; socio-economic; environmental	Utility-scale /country	National electricity utility STEG; Ministry of Industry; Ministry of Environment; National Agency of Energy Conservation; Ministry of Planning and Regional Development; Ministry of Finance	Multi-criteria analysis of electricity- generation mix scenarios	Tunisia
5 Mix	2007 / Diakoulaki and Karangelis (2007)	Coal; natural gas; wind; solar			Utility-scale /country	Regulatory Authority for Energy; public power corporation; Climate Change Abatement (National Observatory of Athens)	Multi-criteria decision analysis and cost- benefit analysis of alternative scenarios for the power generation sector	Greece

6	Mix	2014 / Maxim (2014)	Coal; natural gas; CHP; position engine; fuel cell; hydro; wind; geothermal; solar PV; solar thermal; biomass; nuclear	1. Hydro; 2. Wind on-shore; 3. Solar PV	Economic; technological; environmental; socio-political	Utility-scale / country	Energy industry professionals	Sustainability assessment of electricity-generation technologies using weighted multi-criteria decision analysis
7	Mix	2002 / Afgan and Carvalho (2002)	Coal; solar thermal; geothermal; biomass; nuclear; solar PV; wind; ocean; hydro; gas			No size specification	Not specified / literature review	Multi-criteria assessment of new and renewable energy power plants
8	Mix	2001 / Mamlook et al. (2001)	Fossil fuel; hydro; wind; solar; nuclear	1. Solar; 2. Wind; 3. Hydro		Utility-scale / country	Not specified / literature review	A neuro-fuzzy programme approach for evaluating electric power generation systems
9	Mix	2008 / Chatzimouratidis and Pilavachi (2008)	Coal; fossil fuels; natural gas; nuclear; hydro; wind; solar PV; biomass; geothermal	1. Geothermal; 2. Wind; 3. Biomass; 4. Solar PV	Social; socio-economic/-political	No size specification	Utility company; affected communities	Multi-criteria evaluation of power plants' impact on the living standard using the analytic hierarchy process
10	Mix	2009 / Chatzimouratidis and Pilavachi (2009a)	Coal; fossil fuels; natural gas; nuclear; hydro; wind; solar PV; biomass; geothermal	1. Hydro; 2. Geothermal; 3. Wind; 4. Biomass	Technological; economic	No size specification	Not specified / literature review	Sensitivity analysis of technological, economic and sustainability evaluation of power plants using the analytic hierarchy process
11	Mix	2009 / Chatzimouratidis and Pilavachi (2009b)	Coal; fossil fuels; natural gas; nuclear; hydro; wind; solar PV; biomass; geothermal	1. Hydro; 2. Geothermal; 3. Wind	Technological; economic	No size specification	Not specified / literature review	Technological, economic and sustainability evaluation of power plants using the analytic hierarchy process

12	Mix	2004 / Topcu and Uलगin (2004)	Hydro; wind; solar PV; biomass; fossil fuels; natural gas; nuclear	1. Wind; 2. Hydro; 3. Solar PV; 4. Biomass	Technological; environmental; economic; political	Utility-scale / country	Not specified / literature review	Energy for the future: An integrated decision aid for the case of Turkey	Turkey
13	Mix	2012 / Streimikiene et al. (2012)	Nuclear; fuel cell; hard coal; lignite; oil; natural gas; hydro; biomass; solar PV; wind	1. Hydro; 2. Solar; 3. Wind; 4. CHP	Economic; technological; social; political	Utility-scale / country	Not specified / literature review	Prioritising sustainable electricity production technologies: MCDM approach	European Union
14	RES	2011 / Cristobal (2011a)	Wind; hydro; solar PV, thermo; biomass; biofuels	Wind 10–50 MW		Utility-scale / country	Not specified / literature review	A multi-criteria data envelopment analysis model to evaluate the efficiency of the renewable energy technologies	Spain
15	RES	2010 / Heo et al. (2010)	Not specified		Technological; market; economic; environmental; policy	Utility-scale / country	Not specified / literature review	Analysis of the assessment factors for renewable energy dissemination programme evaluation using Fuzzy AHP	Korea
16	RES	2014 / Trolborg et al. (2014)	Wind; hydro; geothermal; solar PV; biomass; heat-pump; energy from waste; wave; tidal	1. Solar PV; 2. Heat Pumps; 3. Wind off-shore	Technical; environmental; socio-economic	Utility-scale / country	Not specified / literature review	Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties	Scotland
17	RES	2013 / Ertay et al. (2013)	Hydro; wind; solar PV; biomass; geothermal	1. Solar PV; 2. Wind	Technological; environmental; economic; socio-political	Utility-scale / country	Not specified / literature review	Evaluation of renewable energy alternatives using MACBETH and Fuzzy AHP multi-criteria methods	Turkey
18	RES	2011 / Datta et al. (2011)	Solar PV; wind; biomass; hydro			No size specification	Not specified / literature review	Green energy sources (GES) selection based on multi-criteria decision analysis (MCDA)	
19	RES	2011 / Cristobal (2011b)	Wind; hydro; solar-thermal; biomass; bio fuels	1. Biomass; 2. Wind; 3. Solar-thermal		Utility-scale / country	Not specified / literature review	Multi-criteria decision-making in the selection of a renewable energy project in Spain: the VIKOR method	Spain

20	RES	2010 / Kaya and Kahraman (2010)	geothermal; solar PV; wind; hydro; biomass	1. Wind; 2. Solar PV; 3. Biomass; 4. Geothermal	Technical; economic; environmental; social	country	Not specified / literature review	Multi-criteria renewable energy planning using an integrated Fuzzy VIKOR & AHP methodology for the case of Istanbul	Istanbul/ Turkey
21	RES	2014 / Ahmad and Tahar (2014)	Hydro; solar PV; biomass; biogas; wind; multi solid waste	1. Solar PV; 2. Biomass; 3. Hydro; 4. Wind	Technical; economic; social; environmental	country	Not specified / literature review	Selection of renewable energy sources for sustainable development of electricity-generation system using analytic hierarchy process for a case of Malaysia	Malaysia
22	RES	2009 / Tsoutsos et al. (2009)	Wind; biomass; hydro; solar PV		Technical; economic; environmental; social	country	Local authorities; potential investors; local communities; academic institutions; environmental groups; government and European Union	Sustainable energy planning by using multi-criteria analysis for application on the island of Crete	Crete/ Greece
23	RES	2012 / Boran et al. (2012)	Solar PV; wind; hydro; geothermal	1. Hydro; 2. Wind; 3. Geothermal; 4. Solar PV		country	Not specified / literature review	The evaluation of renewable energy technologies for electricity generation in Turkey using intuitionistic Fuzzy TOPSIS	Turkey
24	RES	2012 / Lee et al. (2012)	Wind		Machine characteristic; economic; environmental; technical	country	Not specified / literature review	A wind turbine evaluation model under a multi-criteria decision-making environment	Taiwan
25	RES	2008 / Wang et al. (2008)	Stirling engine; gas turbine; gas engine; solid oxide fuel cell		Technical; economic; environmental; social	Small-scale residential building	Not specified / literature review	A Fuzzy multi-criteria decision-making model for trigeneration system	
26	RES	2009 / Cavallaro (2009)	parabolic trough; parabolic DSG; SCR molten salt; SCR saturated St.; SCR phoebus; solar hybrid gas; dish-Stirling	1. SCR molten salt; 2. Parabolic DSG		Utility-scale	Not specified / literature review	Multi-criteria decision aid to assess concentrated solar thermal technologies	

3.4.2 Evaluation criteria in previous MCDA approaches

This section provides an overview of the evaluation criteria, which were used in the MCDA approaches from numbers 1 to 26 in Table 3.3. The listing of publications in column 1 of Table 3.3 was repeated in Table 3.4 in this section to indicate how often criteria appeared in print. The most frequently recurring criteria are listed and the number specifies the publication in which they were published. In cases where criteria were used less than three times, they were categorised under 'Other'.

The criteria in Table 3.4 are divided into categories, namely technical, economic, environmental and socio-political. This was based on the results of 'types of criteria' in column 6 of Table 3.3. The technical category addresses the physical characteristics of the electricity alternative. The economic category investigates the financial feasibility. The environmental category evaluates the impact of the alternative on nature. Lastly, the socio-political category measures the influence on the quality of life of people being affected by the project (Mateo, 2012).

The overview of criteria used in the MCDA approaches are further sub-divided into those used in approaches evaluating, on the one hand, mixed sources and, on the other, only renewable energy sources. Criteria are only noted when they have an occurrence rate in more than three papers. The following provides a brief summary of the findings:

- Technical – the criteria indicate that overall 'efficiency' (n=10), 'capacity factor' (n=8), 'reliability' (n=8) and 'maturity' (n=7) are most frequently evaluated. A strong difference in application between mixed and renewable sources can be seen with 'maturity'. It shows a higher regularity in the case of renewable energy sources.
- Economic – this category shows that 'investment cost', with n=18, is predominantly used, followed by 'fixed and variable operation, and maintenance costs' (n=11) and 'electric costs' (LCOE). A significant difference can be seen with the criteria 'service life' and 'implementation period', which are mostly used with the renewable energy sources.
- Environmental – the most frequently used criteria are the 'external costs', with n=23. The external costs include different types of emissions. Some MCDA approaches specified the various emissions, while others summarised this aspect into one criterion. Further criteria are 'land use' (n=10) and 'noise' (n=4).

- Socio-political – the criteria illustrate that ‘social acceptability’ and ‘job creation’ were most regularly used, with n=10. In addition, ‘loss of life expectancy’ was used in n=6. The criterion ‘social benefit’ was only used in mixed MCDA approaches.

Table 3.4: Review of criteria used in energy planning MCDA approaches

<u>Criterion</u>	<u>General electricity</u>	<u>Renewable energy</u>	<u>Frequency</u>
Technical			
Efficiency	2,6,7,8,10,11	18,20,21,23	10
Reliability	4,5,8	15,16,17,18,22	8
Capacity factor	1,6,10,11,13	14,16,26	8
Maturity		15,16,18,21,22,25,26	7
Available power during peak load	4,5,6	20	4
Safety	8,9	24	3
Primary energy ratio	10,11	25	3
Energy efficiency	1	20,25	3
Others	5	15,17,19,24,25	
Economic			
Investment cost	1,2,3,5,7,10,11,13	14,17,19,20,21,22,23,24,25,26	18
Fixed and variable operation, and maintenance cost	1,3,5,10,11	14,19,20,22,24,26	11
Electric cost (LCOE)	2,4,6,7,12,13	16,18,26	9
Fuel cost	1,3,10,11	20	5
Service life		14,15,18,19,21	5
Implementation period		14,17,19,21	4
Fuel reserve years (sustainability)	1,8,12	23	4
Net present value (NPV)	4	17,24,25	3
Net import % of energy (stability)	1,3,12		3
Contribution to energy independence	3,4,6		3
Others	3,4,7,13	15,16,17,21,25	
Environmental			
CO ₂ emission	1,2,3,4,5,7,9	14,19,20,21,22,25	13
NO _x emission	1,4,5,9	20,25	6
SO ₂ emission	1,4,5,9		4
Particles emission	1,4,9		3
<u>External Cost</u>	<u>1,2,3,4,5,6,7,9,10,11,12,13</u>	<u>14,16,17,18,19,20,21,22,23,25,26</u>	<u>23</u>
Land use	3,6,7,9	16,17,20,21,24,25	10
Noise	3	16,24,25	4
Visual impact	3	16,24	3
Others	4	15,18,24	
Socio-political			
Social acceptability	3,4,6,9	15,16,17,20,21,22	10
Job creation	1,3,4,6,9,13	17,20,21,22	10
Loss of life expectancy (LLE)	1,6,9,13	23,25	6
Social benefits	3,4,8		3
Others	9,13	17,25	

3.4.3 Impact on the MCDA approach for mining corporations

As stated in the objective of this chapter, the second objective is to investigate previous adaptations of the selected research approach to similar cases. This will contribute to the foundation of an MCDA approach, to optimise the evaluation of electricity-generation sources, for mining corporations in South Africa. The literature review provides an overview of how MCDA approaches have been used in energy planning in past years. The following points indicate how they contributed to or affected the identification of the criteria of this chapter:

- Not one MCDA approach in energy planning could be found from the perspective of a corporate entity and, especially not a mining corporation. Consequently, the previously used criteria can only be used as an indication.
- The only energy planning MCDA approach on the African continent was in the northern country of Tunisia. No such approach in energy planning was found in South Africa.
- The overview of previously used evaluation criteria assists in selecting the criteria for mining corporations. As the marketing of renewable energy to mining corporations is relatively new, respondents might not include all-important criteria for renewable sources. The listed criteria of energy planning serve as a check-list and might indicate that further investigations have to be conducted.
- The type of criteria used by previous publications provides a solid indication about which ones are important for the evaluation of electricity-generation sources.
- The globally preferred selection of solar, wind and hybrid technologies provides an indication about the renewable alternatives that should be included in the MCDA approach for mining corporations.

3.5 Conclusion

The preparation of this chapter is justified by two facts. Firstly, the present and predicted struggle with current electricity sources in South Africa has increased the attractiveness of the steadily advancing renewable technologies for mining operations in South Africa. Secondly, previous research has been directed only at investigating the external influences on this market (chapter 2).

The contribution of this chapter has been to assess and select the most suitable research approach for the purpose of this study to include the perspective of mining corporations. The research has shown that the MCDA method is the most suitable approach. No

application of the MCDA method in energy planning from the perspective of corporate or mining entities could be found. Most MCDA adaptations were from the perspective of governmental bodies or general electricity source evaluations without a specific decision – maker’s perspective. In addition, no adaptation of MCDA methods in energy planning was conducted in the South African context. The next step identified within the field of MCDA, the multi-attribute value theory (MAVT), as the most suitable method for adaption in the context of this study. MAVT is the most detailed MCDA method and fulfils all requirements of this research.

This chapter, created the research foundation to evaluate and compare current and renewable electricity-generating options – from the perspective of mining corporations in South Africa. The reason for sub-dividing the work into three research phases was to create a basis for two components: the first component is the current knowledge about the influences on the potential of renewables for mining operations in South Africa in chapter 2; the second component selects and assesses the most suitable strategic method to address the main objective of this study in chapter 3. Chapter 5 will adopt the MAVT method based on the foundation created in chapter 2 and feed the model with real-time data. The following chapter describes the adaption process of the MAVT method, which will then be represented in chapter 5.

Chapter 4 Creation process of the MAVT model

4.1 Introduction

The purpose of this chapter is to provide the background information to the reader to understand how the MAVT method of this study was developed for mining corporations in South Africa. The foundation for the creation process was formed in chapter 2 and 3. Chapter 2 presented the decision framework for the mining corporation, which entails a selection of choices with the highest attractiveness the mine can choose from. Chapter 3 discussed the MAVT method as most suitable to analyse and compare a possible fit of renewable electricity sources in the light of the external and internal environment.

Figure 4.1 illustrated the MAVT creation process. The following sections describe each step by providing the literature theory and how it was conducted to create the model presented in chapter 5. The characteristics of the mining corporations participating in this study are introduced in the beginning. It is noteworthy that throughout the whole creation process, emphasis was put on the interconnectedness of all steps. When and where new information was gained affecting a previous step, the whole process was revised.

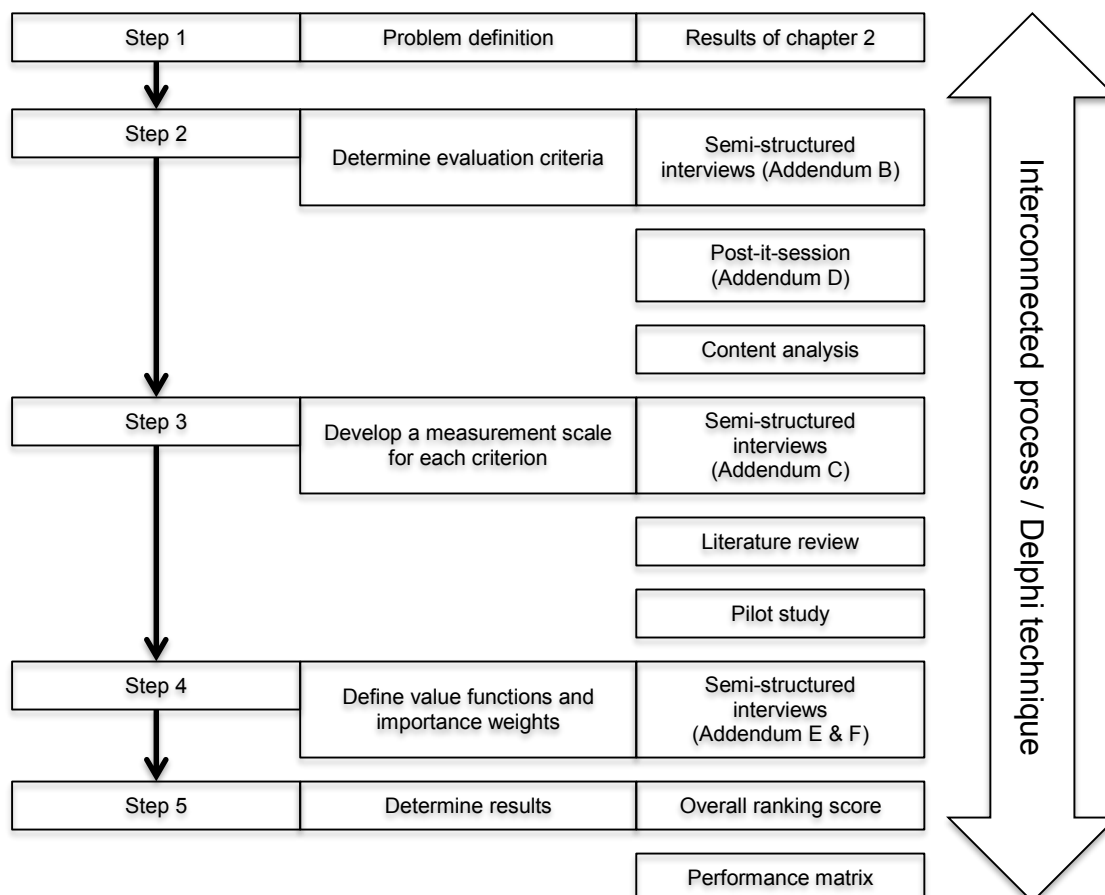


Figure 4.1: The Multi-attribute value theory process

4.1.1 Profile of mining corporations

Four different mining corporations were included in the research, as illustrated in Table 4.1. The respondents were electrical engineers and, in one case, the category manager (electric engineering background) of a utility supply chain with responsibility for one to six mines. Emphasis was placed on gaining information from a variety of mines with different resources, sizes and targets in order to gain optimal insight. The resources mined were gold, coal, chrome and zircon. The average annual electricity consumption per mine varied between 4,2 GWh and 2,752 GWh. As the Eskom tariff alters according to certain factors like seasons or day times, the yearly average price was stated for the sake of simplicity. Three mines were connected to the grid, with diesel generators as backup systems. One of the mines was running on diesel generators and had realised a 1 MW solar PV plant. Two other corporations were conducting a solar PV and on-shore wind power feasibility study.

Table 4.1: Characteristics of mining corporations interviewed

Characteristic	Mining corporation 1	Mining corporation 2	Mining corporation 3	Mining corporation 4
Job description	Energy engineer	Category manager: Utilities Supply chain	Energy engineer	Energy engineer
Type of resources	Gold	Coal	Chromium ores	Zircon
Number of mines represented	3	6	1	1
Average yearly electricity consumption	2752 GWh	701 GWh	4,2 GWh	16,8 GWh
Electricity costs as a percentage of total operational costs	20%	–	–	–
Price per kWh to Eskom	0,72 cent per kWh (yearly average)	0,71 cent per kWh (yearly average)	Not set yet, as connection had been established only recently	No connection
Percentage of electricity supplied by Eskom	100%	100%	70% (30% Solar PV)	0%
Present on-site sources	Diesel	Diesel	Diesel / Solar PV	Diesel
Backup system or fulltime use	Backup	Backup	Diesel = backup Solar PV = fulltime	Base load
Reason to invest	Save costs and more independence	Not feasible	Diesel savings	Diesel savings
Year of realisation	Feasibility stage (10 MW Solar PV)	-	2012 (PV)	Feasibility stage (Wind power)

4.1.2 Step 1: Problem definition

4.1.2.1 Stakeholders

The business model has great influence on the type and number of stakeholders involved to establish an electricity source for mining operations. All stakeholders and their influence on the decision-making process have to be identified to ensure that the best possible solution can be found (Boyse et al., 2014). The selected model of self-generation and own investment involved three main stakeholders, namely the mining corporation, the project developer, and the legislative and regulatory body.

The mining corporation was the main stakeholder for the purpose of this research, as it is the decision-maker regarding a possible project realisation. The decision-makers have to cover two main areas, namely operations and finance. However, the electrical engineer is responsible for the financial and operational evaluation of sources. Electricity generation is not the core business of mines, which would make it difficult for operational and financial managers to evaluate their potential. Decision-makers selecting an alternative from an operational perspective will make use of criteria that ensure the generating source will satisfy the electricity demands of the mine (Cookie et al., 2007). Decision-makers selecting an alternative from a financial perspective will make use of criteria to find the most feasible alternative for electricity generation at the mining location (Goh et al., 2014).

The project development company is responsible for the realisation of the alternative. The companies represent the different electricity sources and are going to provide the data necessary to feed the evaluation criteria to execute the MCDA approach. The developer has no direct influence on the decision-making, and can only affect the attractiveness of the project (Lerro, 2011; Aslani, 2014).

The regulatory and legislative body in South Africa dictates the framework regarding the business model of how electricity projects will be realised. As previously stated, according to this framework, the model of self-generation was selected as most lucrative. It further influences the actual development of the project with factors like compulsory environment assessments, which also considers the surrounding communities (Lerro, 2011; Frost, 1995).

4.1.2.2 Decision framework

To be able to compare renewable with current sources, it is important to define the exact characteristics of the type of alternatives available. The purpose for specifying the selection standards of alternatives is to create more transparency in the process of analysing and evaluating them in comparison with each other (Stewart and Belton, 2002). In cases where alternatives are too different in nature, it becomes more difficult and less informative to compare them according to the same criteria (Keeney, 1996).

Chapter 2 has investigated the influences on the market of renewable sources for mining corporations in South Africa to reveal their potential. Based on this research and the previous MCDA applications in energy planning, solar PV, on-shore wind power and 'hot dry rock' geothermal power were selected as the renewable sources with the greatest potential. Owing to the intermittency, especially of solar PV and wind power, and the relative constant electricity 24hour demand of mining operations, hybrid versions with current electricity sources were identified as the best options.

In addition, based on the current legislative and regulatory framework in South Africa, the business model of self-generation⁸, in the form of own investment or a power purchase agreement, has the greatest potential. As the purpose of the development of the MCDA for mining corporations was to create more transparency, own investment was selected. The reason for this choice was to focus the attention on the performance of the technology and not on third parties (Boyse et al., 2014).

Decision-makers at mining corporations were, therefore, asked to list the evaluation criteria, which they would use to evaluate the following electricity sources:

- Diesel generator
- Hybrid diesel generator/solar PV
- Hybrid diesel generator/on-shore wind power
- Hybrid diesel generator/geothermal power
- Eskom grid connected
- Hybrid Eskom grid connected/solar PV
- Hybrid Eskom grid connected/on-shore wind power
- Hybrid Eskom grid connected/geothermal power

⁸ The mining corporation develops its own on-site renewable generation source (Boyse et al., 2014).

4.1.3 Step 2: Determine evaluation criteria

4.1.3.1 Criteria characteristics and requirements

A decision table was developed to illustrate the evaluation criteria revealed through the interviews and previous research (see Table 5.1). The table of mining corporations evaluating different alternatives for electricity sources had to be conducted according to certain characteristics. The decision table was based on the results of the post-it mind-maps from the interviews with decision-makers. In order to identify a clear structure and to use the criteria for further analysis in a multi-criteria decision analysis approach, specific requirements had to be fulfilled by each criterion (Stewart and Belton, 2002):

- Value relevance – this states that the decision-maker has to be able to relate the concept to the aim of the mining corporation, which enables him or her to define a clear preference for the criterion.
- Understandability – this implies that the criterion has to be clearly identified and explained. Each person involved in the decision-making process has to know the exact meaning to prevent any confusion and misleading results (Edwards et al., 2007).
- Measurability – this indicates that it has to be possible to measure each criterion in a consistent manner according to the alternatives being analysed. As the decision table is the foundation for an MCDA analysis, this requirement is important to create meaningful results.
- Non-redundancy – this signifies that there should not be more than one criterion measuring the same factor. A negative result would be to have faulty results, e.g. one factor has too much weight because it was counted more than once (Edwards et al., 2007).
- Judgmental independence – this means that the one criterion should not have significant influence on the performance of another criterion (Loken, 2007).
- Balancing completeness and conciseness – this states that all aspects of alternatives in a decision-making process have to be addressed by the selected criteria. However, when selecting too many criteria, the researcher has to beware of omissions in order to consider the previously mentioned requirements (Edwards et al., 2007; Loken, 2007).
- Operationally – this implies that criteria should not be only theory-based, but should also be practically proven.

4.1.3.2 Interviews to determine criteria

The first step of the field work was to identify the criteria mining corporations use to evaluate the selected electricity sources. A qualitative research focus was applied in the form of semi-structured interviews. This approach was preferred owing to the exploratory nature of the research. According to Zikmund and Babin (2010), qualitative research addresses the objective through techniques that allow the researcher to gain an in-depth insight without depending on numerical measurement. Nevertheless, findings can rarely be applied to the whole population, as the whole population would not be interviewed. The advantage of semi-structured interviews is that direction would not be lost and the pre-prepared framework would ensure that all questions are asked (Newton, 2010).

The semi-structured interview is especially effective with busy executives and management. Such interviews are suitable for eliciting responses about basic market intelligence, such as trends in technology, industry structure, market demand, competitive activity and similar information. The open structure would also ensure that unexpected facts or attitudes could be pursued easily (Kumar et al., 2002).

The research included a sample of four different mining corporations. The respondents were decision-makers or people who detailed knowledge about the criteria that the mining corporation used to evaluate possible electricity sources. The respondents were firstly interviewed face-to-face to elicit the information about the evaluation process (see Addendum B). The main part of the interview used a post-it session to generate the information in a structured manner (see example Addendum D). The semi-structured interview questionnaire ensured that aspects were considered in the session (Newton, 2010).

The identified criteria were used to construct a decision criteria table, which illustrated the relevant criteria of the mining corporation to evaluate possible electricity sources. The collected data were analysed and sorted following the procedures of content analysis. The coding was used to reduce the number of individual responses to a few general categories and themes of answers (Zikmund and Babin, 2010). If two or more of the respondents mentioned a criterion, it was added to the study. The transformation from the mind-map to the table was conducted according to the requirements for criteria in section 4.1.3.1. A verification approach was used, which meant sending the constructed table back to the respondents via e-mail to get confirmation that it reflected their practices accurately. The

verification approach was in essence a series of sequential rounds – interspersed with controlled feedback – that seek to gain the most reliable consensus of opinion of respondents.

4.1.4 Step 3: Develop a measurement scale for each criterion

The third step was to develop a scale for each criterion. These scales are summarised in Table 5.5 in chapter 5. A local numerical scale was established for the 11 measurable criteria. A local scale entails all values of alternatives analysed, from the worst to the best. An example is provided in Figure 4.2 in the following section. The reason for developing local scales is the fast-changing environment where values, which are based on factors like technological progress (Stewart and Belton, 2002), alter. This makes it impossible to use global scales again.

A global qualitative scale was developed for the remaining five criteria to make comparability possible (Stewart and Belton, 2002). A pilot study was conducted with two experts, one from the renewable field and another from the mining industry, to ensure that the qualitative scales were interpreted consistently. The data for the electricity sources (see section 5.2.3) to feed all criteria and to develop the scale were revealed in cooperation with four mining corporations and five different energy companies, which have specialist knowledge of one or more of the sources. The data were backed up with professional literature to ensure accuracy.

4.1.5 Step 4: Define value functions and relative importance weights

The fourth step was to develop the value functions and assess the relative importance weights of each criterion. The value function reflects the preference of the mining corporation as the decision-maker (Stewart and Belton, 2002). Figure 4.2 provides an example of the operating and maintenance (O&M) cost value function. The coloured sections are explained in section 5.2.4. The vertical axis represents the value to the respondent, from worst (0) to best (100). The horizontal axis gives the scale for the specific criteria. The worst value is situated on the left with 0 value points while the best value is situated on the right with 100 value points.

The procedure for all four mining corporations was the same. All respondents had to go through all criteria and were asked three questions. Firstly, they had to identify the point on the scale, which is half way in value (50) for them. If there was no preference, the point

would stay in the middle and a linear function would be the result. In the case of the examples, an initial cost reduction was more important – which results in a convex function. A more convex curve would represent a stronger preference. A possible reason for the more convex curve could be a tight budget, and the tighter the budget the more convex the function would be, as the higher prices cannot be afforded. Question two and three had the same procedure between the value points of 0 and 50, and 50 and 100. For each value function the average of the four responses was taken.

The possibility of statistical analysis was limited as the sample size was relatively small. To be able to identify tendencies and detect outliers, the theory of quartile calculations was used and adjusted for the purpose of this research (Creswell, 2014). The average of the responses was calculated if all scores were within a range of 25 points on the 0-100 scales. This assured that all averaged responses had the same tendency. No outliers were detected throughout the research.

The reason for translating all criteria into scales from 0–100 was to reveal the respondents' value and to equalise numbers for result calculations (Stewart and Belton, 2002). The value score (vertical axis) for each criterion was determined at the rectangular crossing point on the value function, based on its numerical value (horizontal axis). In Figure 4.2, an electricity source with O&M costs of 15 euros would get a value score of 73.

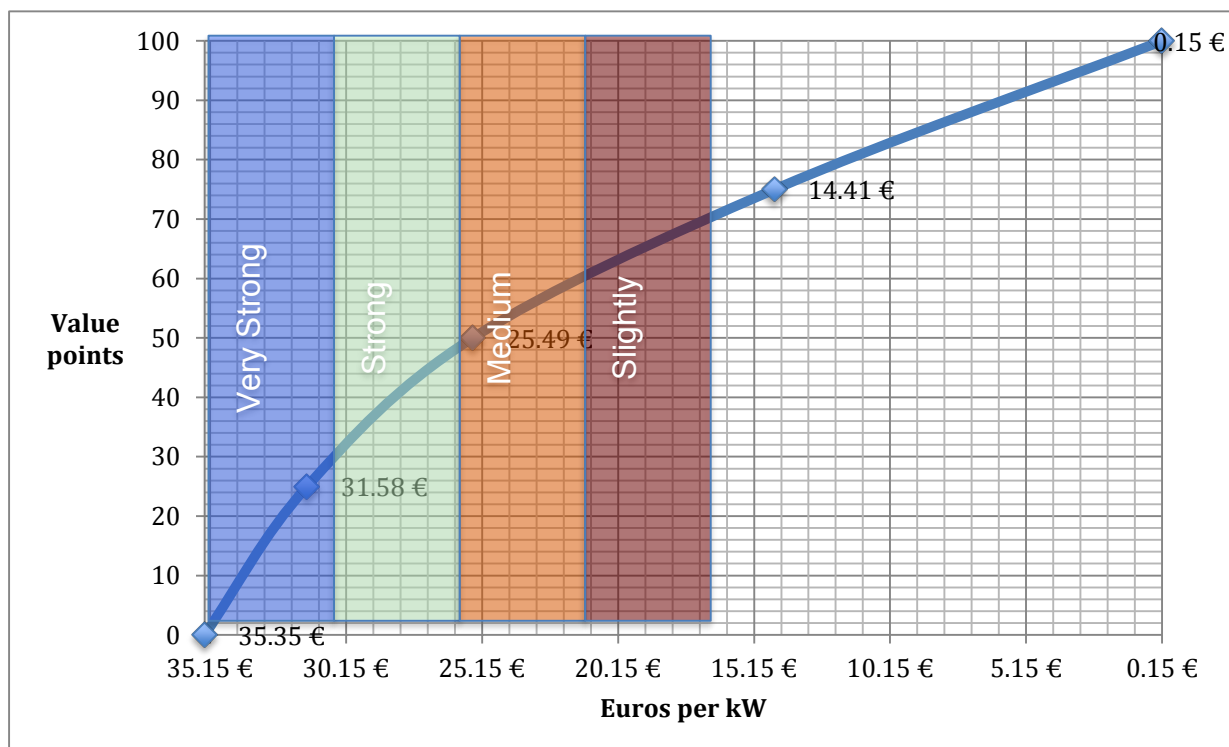


Figure 4.2: Example of O&M cost value function

The relative importance weight shows the magnitude of influence that a single criterion contributes to the final decision. The procedure entailed two stages. In the first stage, the importance weight within each category, namely economy, technology, environment and social, was identified. The questioning was always conducted in the same way. The respondent first had to identify the most important criterion; this received 100 points, followed by the second most important with less than 100 points, depending on how much less it was influencing the decision. The second stage entailed rating the categories themselves, again starting with the most important one with 100 points. To obtain the overall relative importance weight, the weight of each criterion was multiplied with the corresponding category weight (see Addendum H) (Ishizaka and Nemery, 2013).

4.1.6 Step 5: Determine results

This chapter produced two forms of results, which are discussed in section 5.3. First, an overall score for each electricity source is presented. The score was calculated by multiplying the relative importance weight of each criterion with the corresponding value score. The multiplied scores of each criterion were added up to receive the overall value of the electricity source. The scores were normalised and measured against the best performing source with 100 points. The second result is represented in two matrix diagrams for each electricity source. The matrix illustrates the performance of all criteria for each source. One matrix includes while the other excludes the relative importance weights.

4.2 Conclusion

The purpose of this chapter was to describe the literature theory and creation process of the MAVT model. The creation process consisted of 5 interconnected steps. Firstly, the theory from the MAVT method was stated each step, followed by the practices for the model of this study. The information for step one, the problem definition, was drawn from the results of chapter 2. The following steps were mainly based on primary research while secondary literature was used to back up the information. Throughout the process, 4 mining corporations owning several operations and 5 energy companies provided the main input data including two to three interview stages. In the process, experts from the mining and energy field provided extra input (see Addendum A).

The information provided in this chapter assists the reader to understand the implementation process of the model in the following chapter 5. Chapter 5 begins by

introducing the data collected based on the steps described in this chapter. Thereafter, the data is implemented in the created MAVT model and results are presented.

Chapter 5 A mining perspective on the potential of renewable electricity sources for operations in South Africa: A multi-criteria decision assessment⁹

5.1 Introduction

This chapter sets out to implement the selected MAVT method, which was selected in chapter 3 and developed in chapter 4. Previous research in chapter 2 identified non-grid connected solar PV, on-shore wind and geothermal power in hybrid versions along with the current on-site diesel generators and grid-connection to Eskom as most lucrative (see section 2.7). The choice of these hybrid versions was based on the constant electricity demand of mining operations and the intermittency of the renewables. The business model identified was self-generation via own investment. All further information to implement the MAVT method was gathered in cooperation with mining corporations, and renewable and conventional energy companies in order to use real-time data.

The purpose of this chapter is to analyse and compare the strengths and weaknesses of these potential electricity sources, according to a possible fit to the specific needs of mining corporations and from their perspective. To optimise the learning process for mining corporations to equip them with an understanding of renewable energy technologies and for energy companies to learn how to approach these potential new customers, more research has to be conducted (Day, 2014; Judd, 2014b; Steinhäuser et al., 2012).

The research objectives are illustrated in Figure 5.1. The first was to provide the reader with the evaluation criteria and the real time data to feed the model. The data was gathered through primary research and was backed up with professional and academic literature. The second objective was to adapt the selected MAVT method. Based on the third objective, the results of the adapted MAVT method were analysed to identify strengths and weaknesses of the selected sources. The last section investigated the

⁹ The chapter originates from an article, which was prepared for the *Journal of the Southern African Institute of Mining and Metallurgy*.

sensitivity of the method to possible changes to the results when alternating key input data.

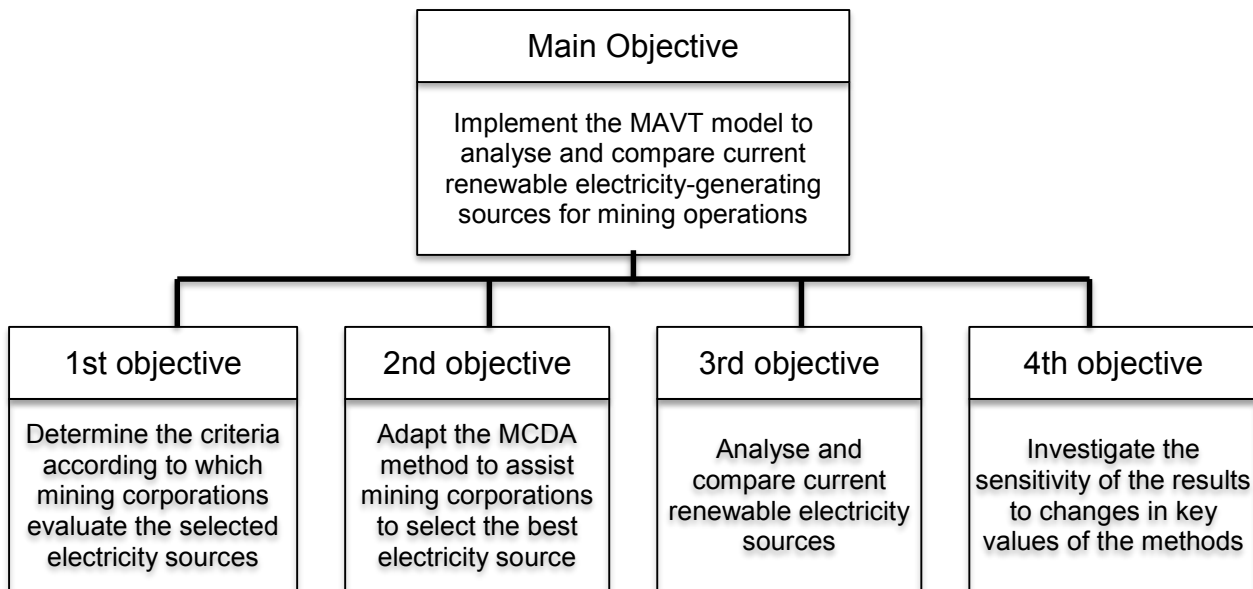


Figure 5.1: Research objectives

5.2 The MAVT for mining corporations to evaluate electricity sources

5.2.1 The decision criteria

The interviews with the mining corporations to reveal their evaluation criteria were based on the following framework (see section 4.1.2.2):

- The electricity sources available were diesel generator; hybrid diesel generator/solar PV; hybrid diesel generator/on-shore wind power; hybrid diesel generator/geothermal power; Eskom grid connected; hybrid Eskom grid connected/solar PV; hybrid Eskom grid connected/on-shore wind power; hybrid Eskom grid connected/geothermal power (chapter 2).
- The business model used to realise the potential project was self-generation in the form of own investment (chapter 2).

The criteria are listed and described in Table 5.1. The first column gives the category and the second the criteria. The economic category included two criteria that measured the economic value of the electricity source, namely levelised electricity costs and net present value. These criteria used several values as part of the calculation. The prediction of fuel costs was new in regard to the literature review. Further new criteria were: supply 24/7, service level, corporate image and effect on community.

Table 5.1: Evaluation criteria of mining corporations

First hierarchy category	Second hierarchy criteria	Description
Economy	Investment cost	Investment cost includes all costs regarding the planning, purchase and installation of the electricity source.
	Operating and maintenance costs	Operation costs entail employees' salaries and the products and services for the system's operation. Maintenance costs ensure that the system is in operating condition, in order to prolong the system's life and avoid failures that result in downtime.
	Fuel / electricity cost	This criterion represents the money spent to produce one kWh. In case of diesel generators, it is the cost of diesel. In regards to grid-connection (Eskom) it is the average kWh tariff.
	Prediction of fuel costs	This criterion provides a prediction of the fuel price in 5 years, consumed by the electricity source to produce electricity.
	Prediction of initial investment costs	This criterion provides an estimation of how the initial investment cost will develop in 1 year. If the technology is relatively new, possible price drops can be expected.
	Levelised electricity cost	This criterion measures the cost per kWh including all costs incurred by the initial investment till the end of the predicted lifetime – which is placed in relation with the projected output of kWh in the same time span. Included: Depreciation; Interests; Loan; Initial investment; Operating and maintenance costs; O&M escalation; Rest value. Discount rate; Initial kWh; System degradation; Tax rate; Change of fuel costs; Number of years
	Net present value	This is a financial method to define the total present value of a series of annual cash inflows and outflows during the lifespan of the asset. The cash flows are discounted back to their present and added up. The final present amount is compared to the initial investment cost.
Technology	Safety	Safety relates to the degree of safety for employees working on site.
	Implementation period	The implementation period is the amount of time needed to realise the project.
	Reliability	Reliability is defined as the capacity of a system to perform as designed and planned.
	Supply 24/7	Most mining operations need a day and night (24-hour) electricity supply.
	Maturity	Maturity refers to the development stage of the technology. The stages range from 'only tested in laboratories' to 'close to reaching the theoretical limits of efficiency'.
	Service level	Service level measures the availability of experts and spare parts to repair damaged equipment.
Environment	CO ₂ emission	This represents the measurement of the emission of a colourless, odourless and tasteless gas, which is mainly emitted through the combustion of coal, oil and gas.
	Noise	Noise is the machine-created sound that disrupts human and animal daily life.

	Land requirement	This criterion represents the amount of land that the electricity source requires to produce a certain capacity.
Social	Job creation	Job creation means the number of people employed during the life cycle of an energy system.
	Corporate image	Corporate image represents the possible impact of the electricity source on the corporate identity in the minds of diverse publics, such as customers, investors and employees.
	Effect on community	This criterion refers to the possible impact on the surrounding residents, after the decision to close the mine. The community could further utilise the electricity source.

It is important to mention that the criteria listed in Table 5.1 represent a summary of all criteria used during the evaluation process, and that most had been applied in other energy planning evaluations at various points in time. The sequence started with technological criteria, aimed to ensure that the potential electricity source could satisfy the electricity requirements of the mining operation. Thereafter, technologies, which passed the technical criteria, were analysed according to economic criteria. All sources were analysed according to the selected business model of self-generation. Lastly, environmental and social criteria were evaluated.

Mining corporations have peculiarities not found in previous MCDA evaluations. Firstly, mining operations are more profit-oriented business entities in comparison to national electricity providers. Therefore, criteria like initial investment cost, which can have a considerable influence on the balance sheet in the first years, have higher priority for mining corporations than for electricity providers (Van Staden, 2015; Wouter, 2014; Wirth, 2015). Secondly, owing to the limited mix of electricity sources and the requirement of constant electricity supply, the criteria of reliability and supply 24/7 are more important to mines. Both were, therefore, used as pre-requisites in the choice of the type of electricity source to be evaluated in Table 5.1. Another criterion that had to be considered, which did not feature in previous evaluations, was the predicted lifespan of the mine, as this factor has a considerable influence on the economic criteria and, consequently, on the feasibility of the project.

5.2.2 Selected electricity sources

This section introduces the electricity sources that were considered for possible solutions at mining operations. As mentioned earlier, a previous research by the author argued that

the selected renewable sources in hybrid versions with current sources presently have the highest potential for mining corporations in South Africa. Table 5.2 briefly describes each source and provides specifications of the exact type of technology used. The type of technologies was recommended by the energy companies supporting this study.

Table 5.2: Electricity sources

Type	Description	Specification
Diesel generator	Baseload diesel generators were considered for the purpose of this research. The reason for this was to consider the source as its own and not as a backup.	The type of diesel generators considered had 16 cylinders, 50 Hz and 1 500 rev/min. This type has a baseload output of 1 500 kVA, with a range of 100 kVA depending on the exact model.
Eskom	Eskom is South Africa's state-owned electricity producer and supplier. The megaflex tariff was used, as it applies for large-scale customers of greater than 1 MVA.	A 50 km distance to the next Eskom-Hub was assumed. A 66 kV line was considered to establish connection.
Solar PV	Horizontal single-axis solar tracker devices were used as the data for this research. The reason for this was the increased production in comparison to fixed-tilt devices, but still a simpler and robust handling in comparison to multi-tilt devices.	The data calculated on an average annual radiation level of 2 000 kWh/m ² were selected. A capacity factor of 26% was used.
Wind	On-shore 2 MW wind turbines with an electrical frequency of 50 Hz were used.	The data were calculated on an average annual wind speed of 600 W/m ² . A capacity factor of 30% was used.
Geothermal	The 'hot dry rock' was selected. The method uses the generation heat due to radioactive decay of granites and gneisses.	The drilling depth of 4 000 m was estimated to calculate the data for South Africa. A capacity factor of 85% was used.

5.2.3 Key values used for calculations

This section presents two different types of tables. Table 5.3 represents the general values, which were used for all electricity sources analysed, especially for the economic criteria. Applying the values ensured that the same foundation was used to compare sources. Owing to the relatively young market and the experimental stage in which mining corporations find themselves regarding renewables, a smaller project size of 10 MW was selected. Each value was discussed with all mining and energy companies contributing to this study and all were found to be most suitable. Where required, the values were double-checked with official sources to ensure that they were in line with international standards.

Table 5.3: Basic values of electricity sources

Description	Value
Project size in MW	10
Straight-line depreciation rate	15%
Tax rate ⁴	28%
Discount rate ^{1,2}	10%
Debt percentage	50%

Equity percentage	50%
Years of loan payment ^{1,2}	15
Cost of debt ^{1,3}	13,4%
Number of years ^{1,2}	20
(1) Waissbein et al., 2013; (2) ETH zürich SusTec, 2014; (3) SAPVIA, 2013a; (4) SARS, 2015.	

Table 5.4 provides the specific values of single and hybrid electricity sources. The values were used to calculate the data to feed the criteria of the MAVT method of this chapter in section 5.2.4. The values were again provided by the energy companies and double-checked with professional, official sources. It is important to mention that the current sources, namely diesel generators and the grid connection to Eskom, are considered the main sources. Technological standards, especially the intermittency of renewables, require the current sources to contribute continuously to the supply to ensure a stable system. Diesel generators have higher ratios than the grid-connection to Eskom because of their minimum load ratios (see section 2.2.4). For illustration purposes, a 10 MW hybrid diesel-solar PV project would entail a 10 MW diesel generator and a 7,5 MW solar PV plant.

Table 5.4: Specific values of electricity sources

Description	Diesel	Eskom	Solar	Wind	Geothermal
Annual change of fuel costs in % ^{1,2,3,4,6,11,13,14}	7%	9%	0%	0%	0%
O&M cost escalation in % ^{6,12}	2%	2%	2%	2%	2%
Annual system degradation ^{4,6,7}	1%	0%	1%	1%	1%
Project ratio diesel	1		0,75	0,8	0,8
Project ratio Eskom		1	0,95	0,95	0,95
CO ₂ emission kg/kWh ^{5,6}	0,85	1,005	0	0	0
Land requirement m ² /MW ^{8,9,10}	200,00	15 000,00	24 000,00	30 000,00	16 000,00
(1) IRENA, 2014a; (2) OPEC, 2014; (3) South African Reserve Bank, 2015; (4) Jung and Tyner, 2014; (5) Eskom, 2015a; (6) Lazard, 2014; (7) EIA, 2013; (8) NREL, 2013; (9) NREL, 2009; (10) Kagel et al., 2007; (11) Wouter, 2014; (12) Masters, 2013; (13) Eskom, 2015c; (14) Eskom, 2015b.					

5.2.4 The criteria and value functions

This section presents an overview, illustrated in Table 5.6, of all relevant data regarding the adaptation of the MAVT method for South African mining corporations to analyse and compare current with hybrid renewable electricity sources. The left column of Table 5.6 shows the criteria investigated, followed by the specific data of the electricity source options and, lastly, the results for the relative importance weight and value function. Most of the numerical measured criteria were again double-checked with professional, recognised official sources, including the results of Table 5.3 and 5.4. For calculations with the Eskom tariff, the fact that the network charges stay the same was considered. The use

of renewables only reduces the energy units consumed by Eskom. The network charges were set at 10% of the selected megaflex tariff (Eskom, 2015g).

Table 5.5: Summary of final criteria data

Criteria	Diesel	Diesel & Solar	Diesel & Wind	Diesel & Geothermal	Eskom	Eskom & Solar	Eskom & Wind	Eskom & Geothermal	Relative importance weight	Value function
Economic										
Investment cost per kW ^{1,3,5,10}	€450,00	€1 425,00	€1 330,00	€4 210,00	€400,00	€1 635,00	€1 445,00	€4 865,00	100 (1)	Medium
O&M costs per kW ^{5,8,3,10}	€0,15	€15,15	€10,55	€26,55	€4,00	€23,00	€16,35	€35,35	47 (8)	Medium
Fuel costs per kWh ^{4,8,3,13}	€0,290	€0,230	€0,217	€0,082	€ 0,058	€ 0,045	€ 0,043	€ 0,016	86 (3)	Medium
Prediction of fuel costs / electricity cost in 5 yrs ^{4,12}	€0,407	€0,323	€0,304	€0,116	€ 0,089	€ 0,069	€ 0,066	€ 0,024	85 (4)	Medium
Prediction of initial investment costs ³	0%	12,3%	7,28%	0,0%	0%	13,6%	7,96%	0,0%	21 (15)	Medium
Levelised electricity cost (kWh) ^{1,3,5,5}	€0,373	€0,311	€0,292	€0,158	€ 0,094	€ 0,090	€ 0,085	€ 0,084	37 (12)	Medium
Net present value	-€254 725 448	-€212 271 668	-€199 272 705	-€107 782 002	-€ 70 067 085,60	-€ 66 760 638,17	-€ 62 449 653,96	-€ 60 564 396,82	92 (2)	Slight
Technology										
Safety	9	9,5	7,5	9	8	9	7	8,5	62 (5)	Strong
Implementation period in months	3	12	15	36	36	36	36	36	47 (8)	No
Maturity	9	8	8,5	6,5	7	7	7,5	5,5	43 (10)	Medium
Service level	9	8,5	8	7	10	9	8,5	7,5	50 (7)	Medium
Environment										
Total lifetime CO ₂ emission kg	1 342 766 122	1 067 145 708	890 465 955	325 090 745	1 758 999 240	1 324 091 520	1 089 910 440	253 549 440	52 (6)	Medium
Noise (1 MW) ^{6,9,10,11}	110	100	109	20	20	42	53	20	10 (16)	No

Total land requirement for project m ² /10 MW	2 000	182 000	242 000	130 000	150 000	378 000	435 000	302 000	8 (17)	Medium
Social										
Job creation (10 MW) ^{2,7,9}	12	34	24	14	1	23	13	3	42 (11)	No
Corporate image	5	10	10	10,5	8	11,5	11,5	12	34 (13)	Strong
Effect on community	5	6,5	6	5	5	6,5	6	5	31 (14)	Strong
(1) IRENA, 2014a; (2) IRENA, 2013b; (3) IRENA, 2014b; (4) OPEC, 2014; (5) Fraunhofer ISE, 2013; (6) Jongens, 2007; (7) Jacobson et al., 2013; (8) Lazard, 2014; (9) Matek and Gawell, 2014; (10) Kagel et al., 2007; (11) Vestas, 2015; (12) Wouter, 2014; (13) Eskom, 2015d										

The relative importance weight was normalised according to the most important criteria, namely investment cost with a score of 100. The number indicates by how much more or less weight a criterion influences the final decision. The number in brackets indicates the ranking for illustration purposes. The last column specifies the level of preference in the value function regarding each criterion. All functions were linear or concave, consequently, the column indicates the extent to which the function is convex. The extent was categorised into four levels, very strong, strong, medium and slightly, as can be seen in Figure 4.2 in section 4.1.5. The point moving on 50 points of the value scale was considered. A linear function means the point is in the middle of the horizontal axis and there is no shape. As the point moves further to the left, the convex curve is stronger and, therefore, there is a preference not to pay the high O&M costs.

The numerical criteria data for the hybrid electricity options were calculated for fixed costs according to the project ratios in Table 5.4. For example, the investment cost for a hybrid diesel-solar PV of €1 425,00 was calculated by: $1 \times €450,00 + 0,75 \times €1\,300,00$. The two variable cost criteria, i.e. actual and predicted fuel costs, were calculated according to the electricity contribution, where the renewable electricity has priority and the conventional source is used to satisfy the remaining demand. The levelised electricity cost and net present value entail both scenarios of fixed and variable costs, and consequently, both were considered in the calculations.

In order to understand all data measurements, the following list introduces the criteria measured according to a qualitative scale. A global scale was used, as the scale is set and non-changing. The respondents of mining corporations were asked to rate the corporate image and effect on community criteria, as they are specific to the mining industry. All other data for the qualitative criteria were gathered from the energy companies, owing to their expertise in the field. The scales, which were developed and measured, are presented in Table 5.5.

Table 5.6: Qualitative scales

Safety		
(1) Incidents that hospitalise workers occur frequently	(5) Incidents occur that force workers to rest at home	(9) Incidents causing light injuries occur infrequently
(2) Between 1 and 3	(6) Between 5 and 7	(10) Between 9 and 11
(3) Severe injuries that hospitalise workers occur sparingly	(7) Hard work causes frequent light injuries, but work can be continued	(11) No incidents of any form are expected during the lifetime of the system
(4) Between 4 and 5	(8) Between 7 and 9	
Maturity		
(1) Only performed in pilot plants, where the demonstrative goal is linked to the experimental one, in respect of operating and technical conditions	(5) Well established in the market but further efficiency improvements are expected	(9) Close to reaching the theoretical limits of efficiency
(2) Between 1 and 3	(6) Between 5 and 7	(10) Between 9 and 10
(3) Available on the market, but the improvement rate in coming years is expected to be very high	(7) Technologies could still be improved but are close to maximum efficiency	(11) Technological plateau is reached
(4) Between 3 and 5	(8) Between 7 and 9	
Service level		
(1) More than 4 weeks	(5) 1 week	(9) 1 day
(2) 4 weeks	(6) 4 days	(10) less than 1 day
(3) 3 weeks	(7) 3 days	
(4) 2 weeks	(8) 2 days	
Corporate image		
(1) Negative influence through public media	(7) Negative influence within own company	(13) Positive influence on business partners
(2) Between 1 and 3	(8) Between 7 and 9	(14) Between 13 and 15
(3) Negative influence within the industry	(9) No impact	(15) Positive influence within the industry
(4) Between 3 and 5	(10) Between 9 and 11	(16) Between 15 and 17
(5) Negative influence on business partners	(11) Positive influence within own company	(17) Positive influence through public media
(6) Between 5 and 7	(12) Between 11 and 13	
Effect on community		
(1) The pollution is negatively affecting the health standards	(4) Between 3 and 5	(7) Uplift community by leaving a source of electricity after mine closure
(2) Between 1 and 3	(5) No impact	(8) Between 7 and 9
(3) No effect on health, but factors like noise is lowering quality of life	(6) Between 5 and 7	(9) Uplift community by leaving electricity source and increase quality of life

5.3 Results

5.3.1 The overall ranking of electricity sources

This section represents the analysis and evaluation of the results of the MAVT implemented for the purposes of this chapter. The results are based on the input data introduced in the previous sections. Chapter 4 describes the adapted multi-attribute value theory model of this chapter. Section 5.2.1 provides an overview of the evaluation criteria. Section 5.2.2 – 5.2.3 introduces all key input data used to feed the MAVT model developed.

Two types of results were generated: firstly, the overall ranking of electricity sources analysed and, secondly, the individual performance matrix of each source based on the evaluation criteria. The overall ranking is illustrated in Figure 5.2. The hybrid version, consisting of Eskom with solar PV, was ranked as the best performing source, followed closely by another hybrid version, consisting of Eskom with on-shore wind, and Eskom alone. The following four sources had very similar overall scores: they were the three hybrid versions with diesel generators, and the hybrid consisting of Eskom with geothermal power. The lowest performing source was a diesel generator alone.

From the results in Figure 5.2, it is important to note that the hybrid versions of wind and solar PV along with current sources were always ranked more highly than using current sources alone. The difference between using hybrid applications and using only diesel generators was marked. However, the advantage of using only Eskom was relatively small.

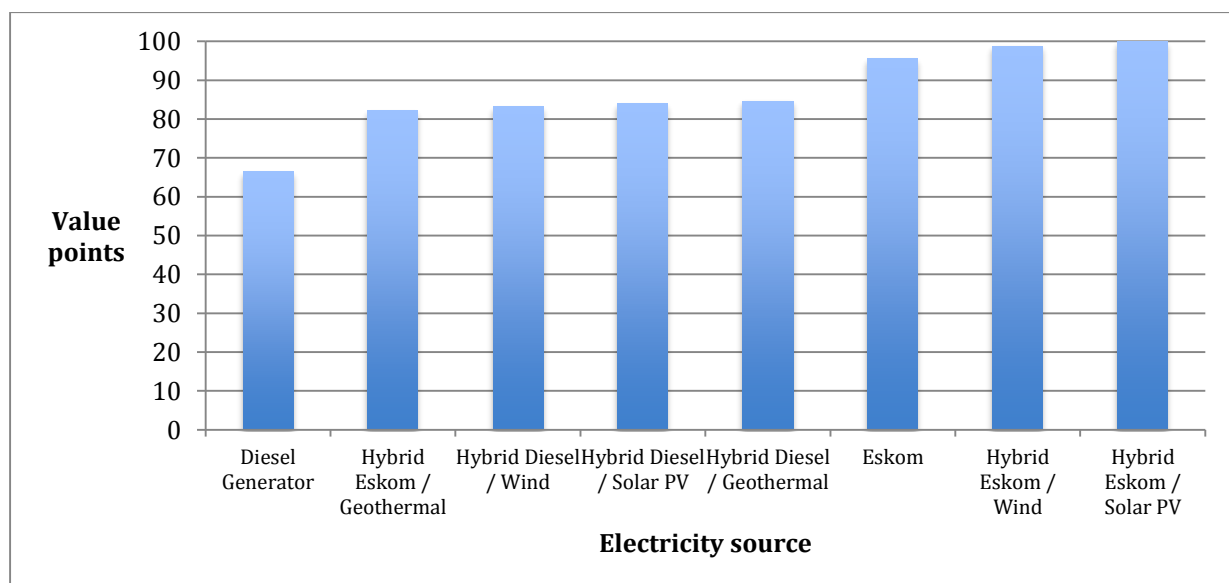


Figure 5.2: Overall ranking of electricity sources

5.3.2 The individual performance of electricity sources

The individual performance of electricity sources is presented in this section. For illustration purposes, two sources are always represented in each figure, giving the score for the currently used source only and for the corresponding hybrid version. Consequently, it is possible to identify and evaluate how exactly hybrid versions performed differently from the currently used sources. The solid shaded area represents the result including the relative importance weights. The dotted lines represent the criteria scores only, excluding the relative importance weights.

The performance matrix for diesel generators and a hybrid version with solar PV is illustrated in Figure 5.3. The advantage of diesel generators was the initial low investment cost, the small space requirement and a short implementation period. However, the running costs, including the expected diesel price increases, were a serious weakness. A hybrid version with solar PV increased initial investment costs and lowered fuel consumption. The net present value indicated that about €44 million can be saved over a period of 20 years using a hybrid version. Further advantages of a hybrid version were lower levelised costs, fewer CO₂ emissions, a better corporate image and a more positive effect on the community.

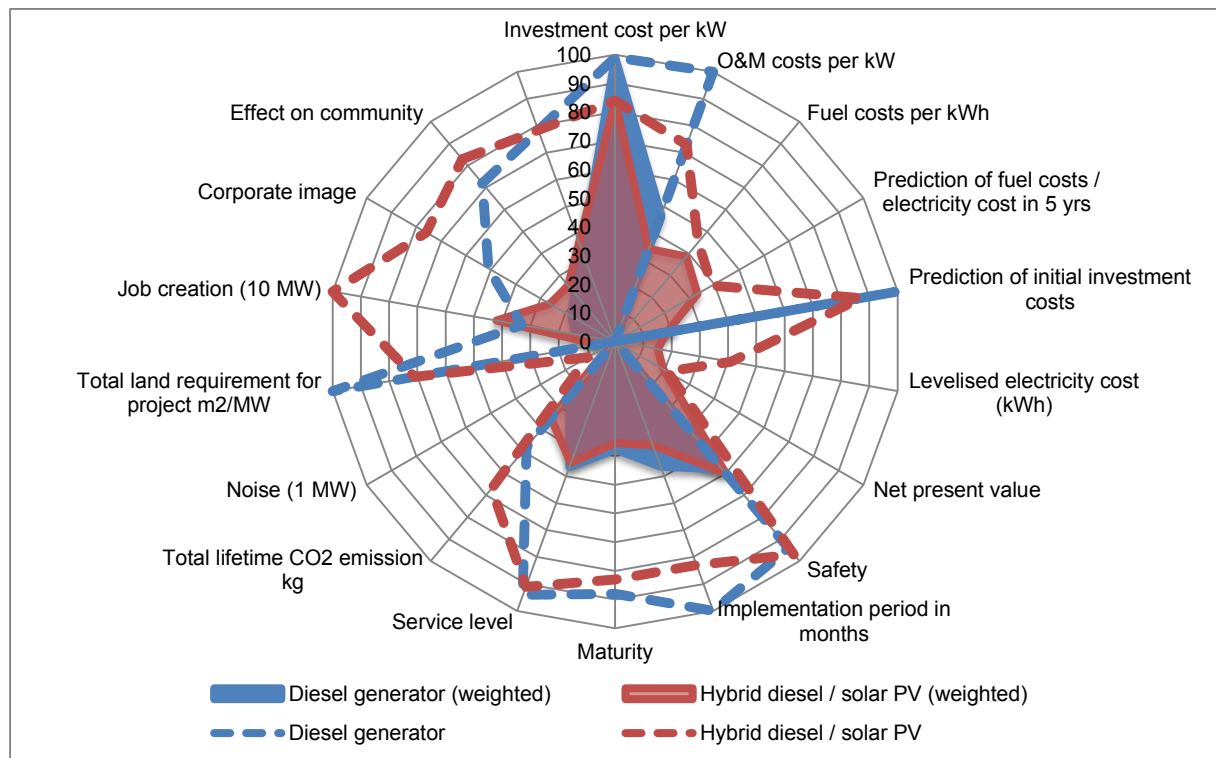


Figure 5.3: Diesel – Hybrid diesel/Solar PV

The performance matrix for diesel generators and a hybrid version with on-shore wind is illustrated in Figure 5.4. This hybrid had great similarities to the hybrid version with solar PV above. The implementation period of 15 months for the hybrid on-shore wind version was slightly longer than the 12 months required for the solar PV hybrid version. Moreover, wind had a slightly lower job creation potential. The long-term net present value savings of a hybrid on-shore wind version in comparison to only diesel generators amounted to about €55 million, with a possible levelised cost reduction of €0,081.

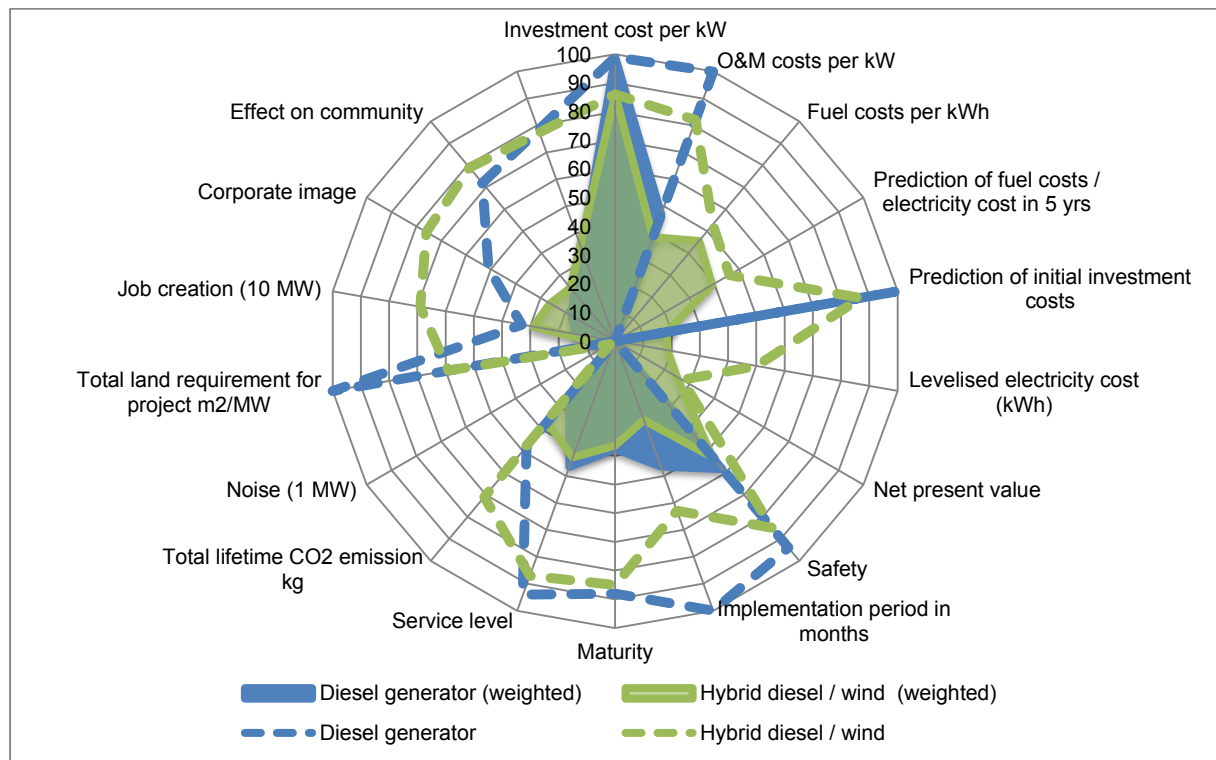


Figure 5.4: Diesel – Hybrid diesel/on-shore wind

The performance matrix of diesel and a hybrid version with 'hard rock' geothermal power in Figure 5.5 showed distinctively different characteristics than solar PV and on-shore wind. The strong advantages were superior fuel-related costs, levelised costs, net present value and CO₂ emission benefits. One reason for the advantages was the baseload characteristic of 85% of geothermal electricity generation. The clear disadvantages were the comparably extremely high initial investment costs and an implementation period of 36 months. The net present savings amounted to approximately €147 million. All three hybrid versions with diesel showed very similar overall scores in Figure 5.2 and a considerably improved rating compared to only diesel generators.

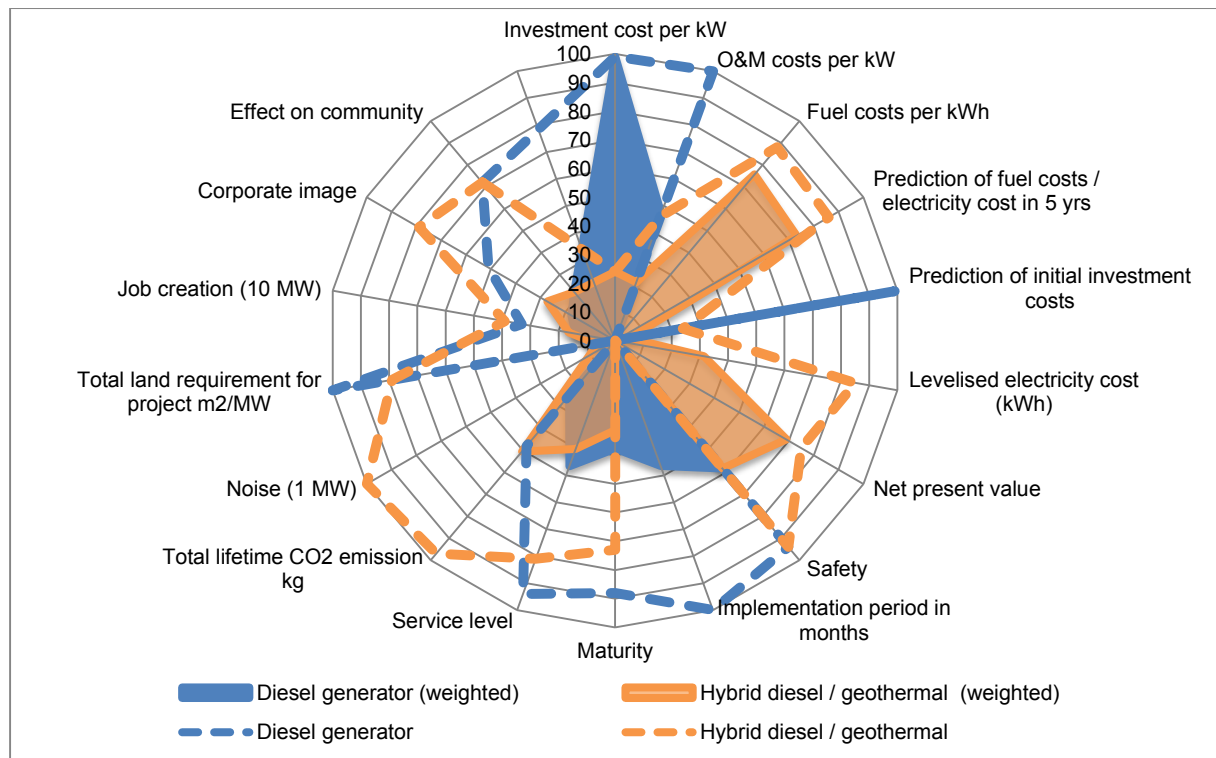


Figure 5.5: Diesel – Hybrid diesel/Geothermal

The following three figures represent Eskom and the renewable hybrid versions. Eskom in hybrid versions with solar PV, on-shore wind and Eskom alone were the best performing sources. As can be seen in Figure 5.2, the improvement of Eskom alone on the hybrid versions was not particularly significant. The hybrid version with geothermal was ranked in the second last position and, therefore, performed worse than Eskom alone.

The reason for the minimal performance improvement can be seen in the matrix of Eskom and a hybrid version with solar PV in Figure 5.6. The disadvantage of the hybrid version was again the initial investment cost and the O&M costs. Slight improvements can be seen in fuel costs, levelised costs and net present value. The hybrid version accumulated a net present saving of €4 million over the time span of 20 years. Further improvements can be seen in respect to job creation, corporate image, effect on community and CO₂ emissions.

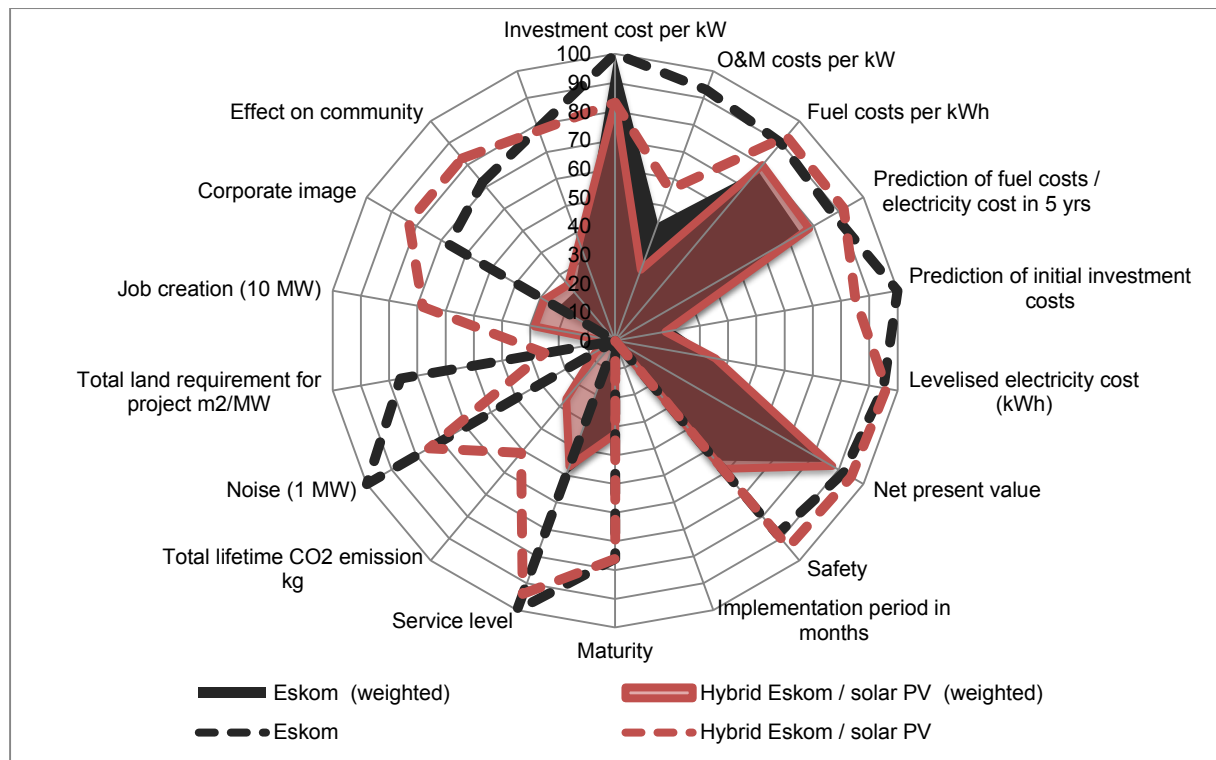


Figure 5.6: Eskom – Hybrid Eskom/Solar PV

The performance matrix for Eskom and a hybrid version with on-shore wind is illustrated in Figure 5.7. The performances on all criteria were very similar to the solar PV hybrid version, which displayed the same pattern as the diesel hybrid versions. The wind hybrid version performed slightly better on all economic criteria and in respect to CO₂ emissions. The net present savings in comparison to Eskom was only €8 million. However, worse performances, especially relating to safety, maturity, job creation and space requirements moved it to the second ranking.

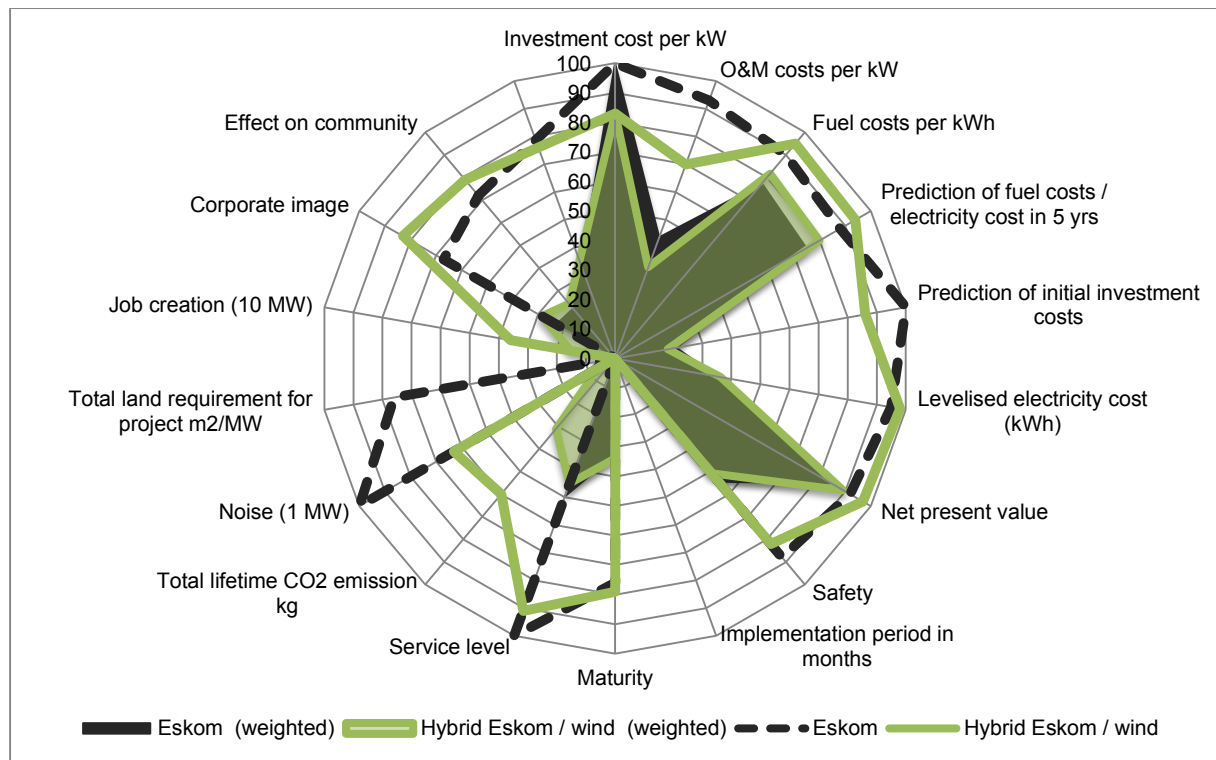


Figure 5.7: Eskom – Hybrid Eskom/Wind

The performance matrix for Eskom and a hybrid version with geothermal power is shown in Figure 5.8. The overall poor ranking can be explained as resulting, particularly from the very high initial investment and O&M costs, which represented the worst values in comparison to the other sources and their high relative importance weights. However, significant long-term benefits lay in having the lowest fuel costs, and were to be earned in respect to levelised costs, net present value and CO₂ emissions. Net present expenses at €60 million were the lowest, and were €10 million less than Eskom only.

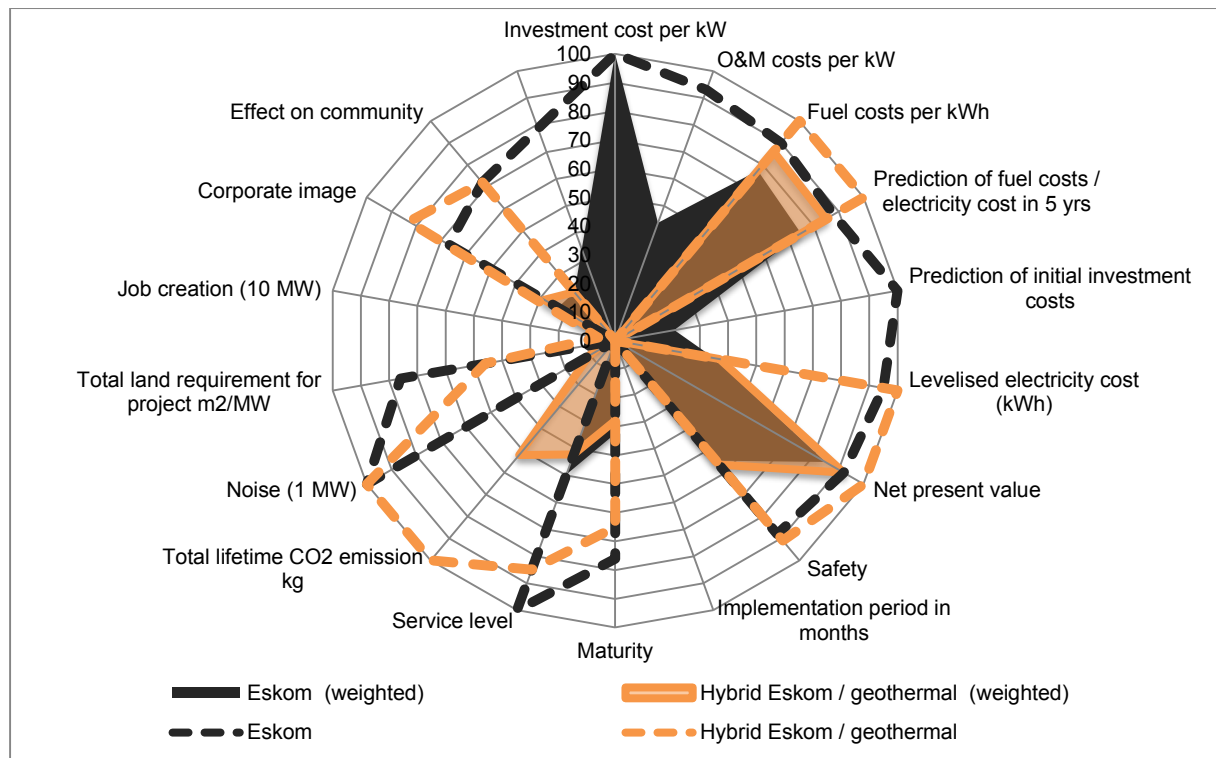


Figure 5.8: Eskom – Hybrid Eskom/Geothermal

5.3.3 Discussion of results

An overview of the strength and weaknesses of current to hybrid renewable electricity sources can be seen in Table 5.7. The table summarizes a chart illustrating the performances of all analysed electricity sources according to the criteria of the created MAVT model. Addendum I provides an overview of the same results but comparing the sources based on each criteria. The relative importance weights were not considered in order to assure a better indication. An extra section was created for the current electricity sources as the performance on two criteria were opposing. It is indicated in brackets, in case one electricity source showed an extreme performance on a criterion. The results showed similar patterns for the use of renewables in hybrid versions with currently used electricity sources. Consequently, they were summarized under “hybrid current/renewables”.

As can be seen in Table 5.7, the move to renewables has a long-term advantage, as it requires a shift from constant high operational cost to an initially high capital investment with low operational expenses, especially for mines running on diesel generators. Considering the currently increasing Eskom tariffs, the benefits of using renewables will increase further. The specific weakness of operating with a diesel generator is high current and predicted fuel costs, levelized costs, net present value and noise. The unique

advantage is the low implementation period, which makes it attractive for mining operations with short life spans. The use of geothermal electricity in a hybrid version has shown the highest long-term benefits (20 years) and the worst short-term performance, especially from an economic point of view.

Table 5.7: Performance overview of current and hybrid renewable electricity source

Electricity source	Strength	Weakness
Diesel generator/Eskom	<ul style="list-style-type: none"> • Initial investment cost • O&M costs (excluding fuel costs) • Prediction of initial investment costs • Service level • Land requirement (diesel generator) 	<ul style="list-style-type: none"> • Fuel costs (diesel generator) • Prediction of fuel costs (diesel generator) • Levelized electricity costs (diesel generator) • Net present value (diesel generator) • CO₂ emission (Eskom) • Noise • Job creation
Diesel generator	<ul style="list-style-type: none"> • Implementation period 	<ul style="list-style-type: none"> • Noise
Eskom	<ul style="list-style-type: none"> • Noise 	<ul style="list-style-type: none"> • Implementation period
Hybrid current / renewables	<ul style="list-style-type: none"> • Fuel costs (geothermal) • Prediction of fuel costs (geothermal) • Levelised costs (geothermal) • Net present value (geothermal) • CO₂ emission (geothermal) 	<ul style="list-style-type: none"> • Initial investment (geothermal) • O&M costs (geothermal) • Prediction of initial investment (geothermal) • Land requirement

Solar PV had the greatest potential, as a vast number of mining areas are in prime solar radiated regions in central South Africa, the service structure is well developed (chapter 2) and it is the best performing source from the perspective of mines connected to the Eskom grid and almost identical to all renewable hybrid versions with diesel generators.

Wind power was ranked second owing to the fact that it only can be applied on a limited scale in the coastal regions of South Africa where there are only few mines. Moreover, the service infrastructure is also well developed (chapter 2) and performance, from the perspective of mines, is only slightly behind that of solar PV. However, the economic performance of on-shore wind is slightly better than that of solar PV.

Geothermal power had the weakest overall potential for mining operations in South Africa. Although it has long-term benefits from the perspective of mines, a considerable initial investment has to be conducted. The source did not outperform Eskom alone and is only minimally ahead of the other diesel hybrid versions. The disadvantage of a relatively young technology of which there is only little experience in South Africa is that it increases the risk of investment. Moreover, service infrastructure has not been developed yet and areas with good geothermal potential northeast of South Africa are well connected to the Eskom grid (chapter 2). Nevertheless, the study has shown a great potential for future development, especially for long-term success, which could be realised with a growing geothermal industry in South Africa.

5.4 Sensitivity analysis

The following sections address how an alternation of the most influential input data would influence the overall results. The variables were selected in accordance with the input of experts from the mining and energy field. The selected ones have high importance weights and are by far the biggest influence on the mining corporations decision-making, due to their impact on the planning horizon.

The selected variables are the systems lifespan, the fuel cost prediction and the forecasted implementation of a CO₂ tax. The lifespan is of interest for mining corporations, as lifespans of mines differ – which has an impact especially on the economic framework of the project. The prediction of tariff increases by Eskom, and fuel and diesel costs have a great influence on economic criteria and were, therefore, double-checked with official sources. A fluctuation of prices is possible and cannot be forecasted as good as for the other variables. However, exact forecasts for the next 20 years can be imperfect, which necessitates an investigation into consequences of the results for worst and best case scenarios. Lastly, the possible impact of a CO₂ tax was considered, as all contributing mining corporations mentioned it as a point of concern.

5.4.1 Lifespan of the project

The lifespans considered in this section are 10 and 5 years. The criteria selected to illustrate the effect on performance are the levelised costs and the net present value, as shown in Figures 5.9 and 5.10. The options with a diesel generator stay in the same order

for both criteria. Nevertheless, the shorter the lifespan the smaller the advantage becomes.

Options with Eskom have a change in ranking on those two criteria. On a 20-year lifespan, all hybrid sources perform better than Eskom alone. On a 10-year span, only the hybrid version with on-shore wind can compete. Based on 5 years, Eskom alone is the best performing option.

Considering all criteria, the overall ranking does not change significantly, as the change of lifespan only affects economic criteria and CO₂ emissions. The hybrid versions of Eskom with solar PV and wind are in top position, followed by Eskom alone. The only change which occurs is the shift of the diesel hybrid geothermal version from fourth to seventh place. The reason for this is the gain in weight of initial investment costs on a lower calculated lifespan, as there is a smaller saving on fuel costs.

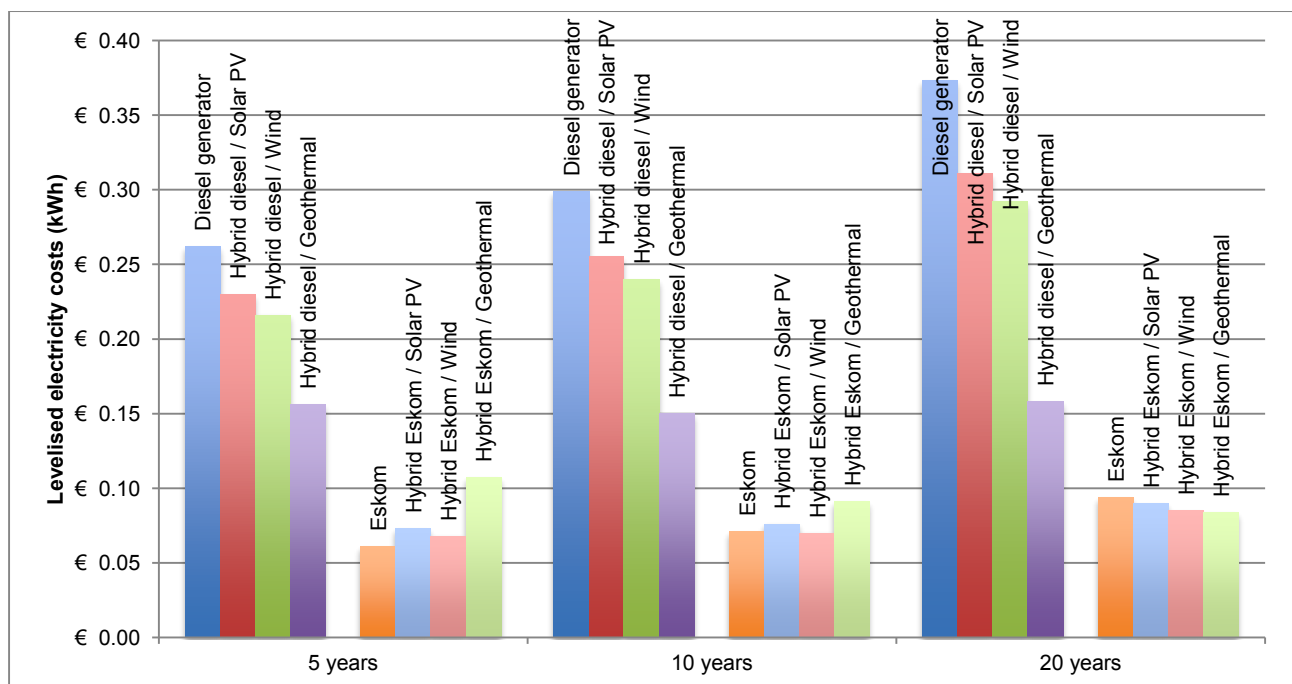


Figure 5.9: Effect of project lifespan on levelised cost of electricity

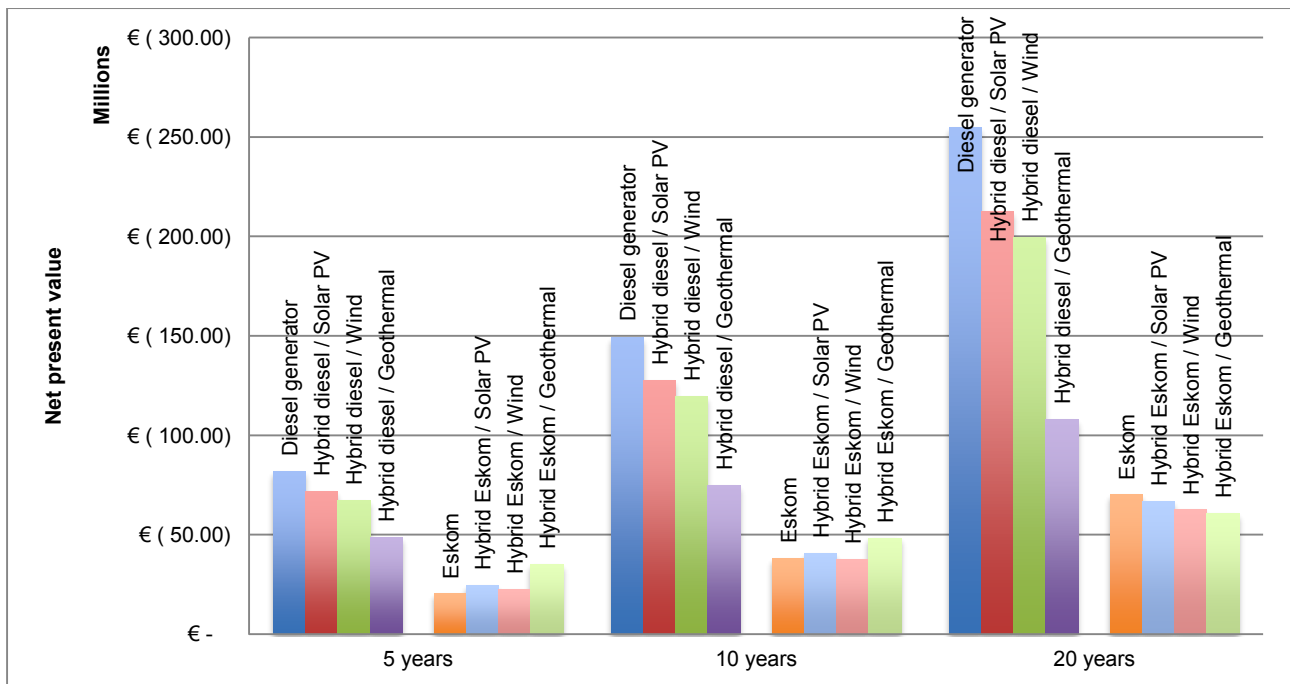


Figure 5.10: Effect of project lifespan on net present value

5.4.2 Eskom tariff and diesel price forecast analysis

The prediction of how fuel and tariff costs of present sources will change over the next 20 years cannot be forecasted precisely. As discussed in section 5.2.2, with the opinion of experts and a literature review contributing to this study, predictions were made. However, as the influence of the forecast on the running costs is considerable, a scenario analysis was conducted and the results are presented in Figures 5.11 and 5.12. For illustration purposes, the levelised cost and net present value criteria were considered.

The diesel generator and hybrid version costs are presented in the top section of Table 5.9. A variation of about 5% of the predicted annual 7% diesel price increase was investigated. The different scenarios did not affect the overall ranking of the sources. The levelised costs showed a great sensitivity to a change in the diesel price. The costs were more than double between best and worst case scenarios. The net present values showed that the usage of renewables lowers the sensitivity to fuel changes. The changes in value from worst to best case were significantly less for the hybrid versions.

Again, the overall ranking for all Eskom versions were not affected by the alternation. It is noteworthy that only the hybrid version with wind could compete with Eskom alone in the best case scenario based on the two criteria. In the other scenarios, Eskom is the most

expensive version. The greater independence from tariff changes was still noticeable, but not as big as with diesel versions.

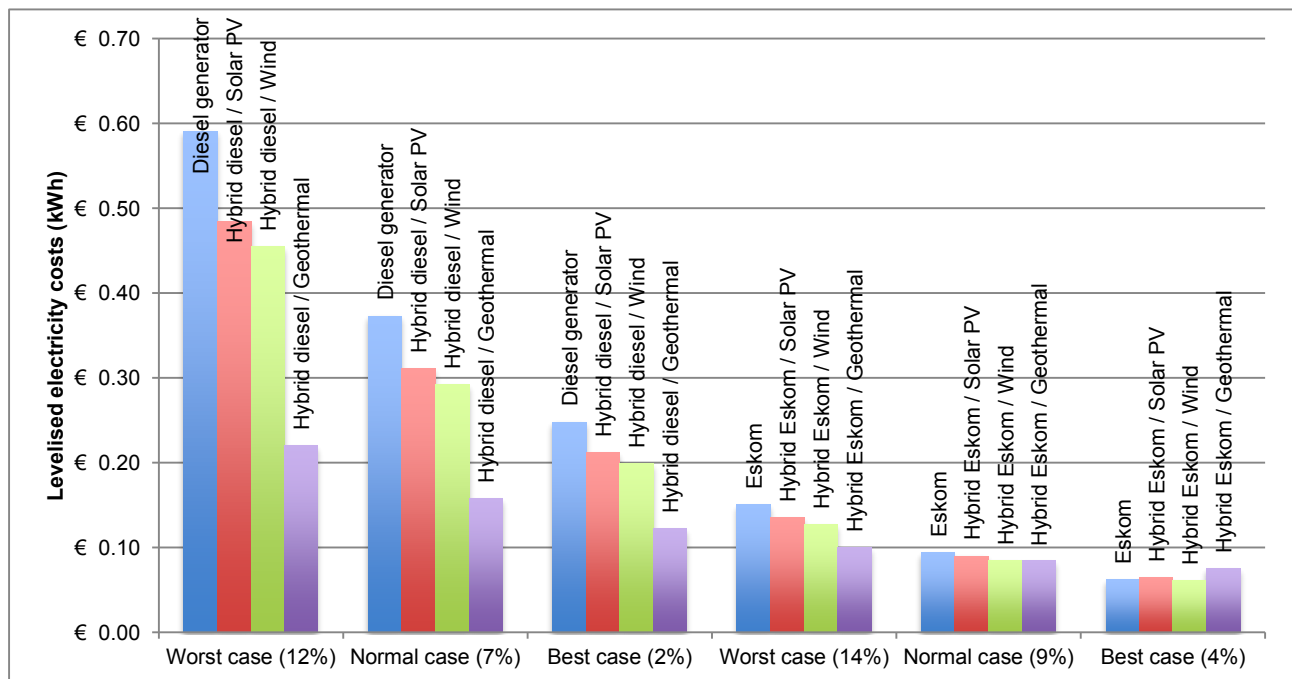


Figure 5.11: Effect of diesel price and Eskom tariff prediction on levelised electricity costs

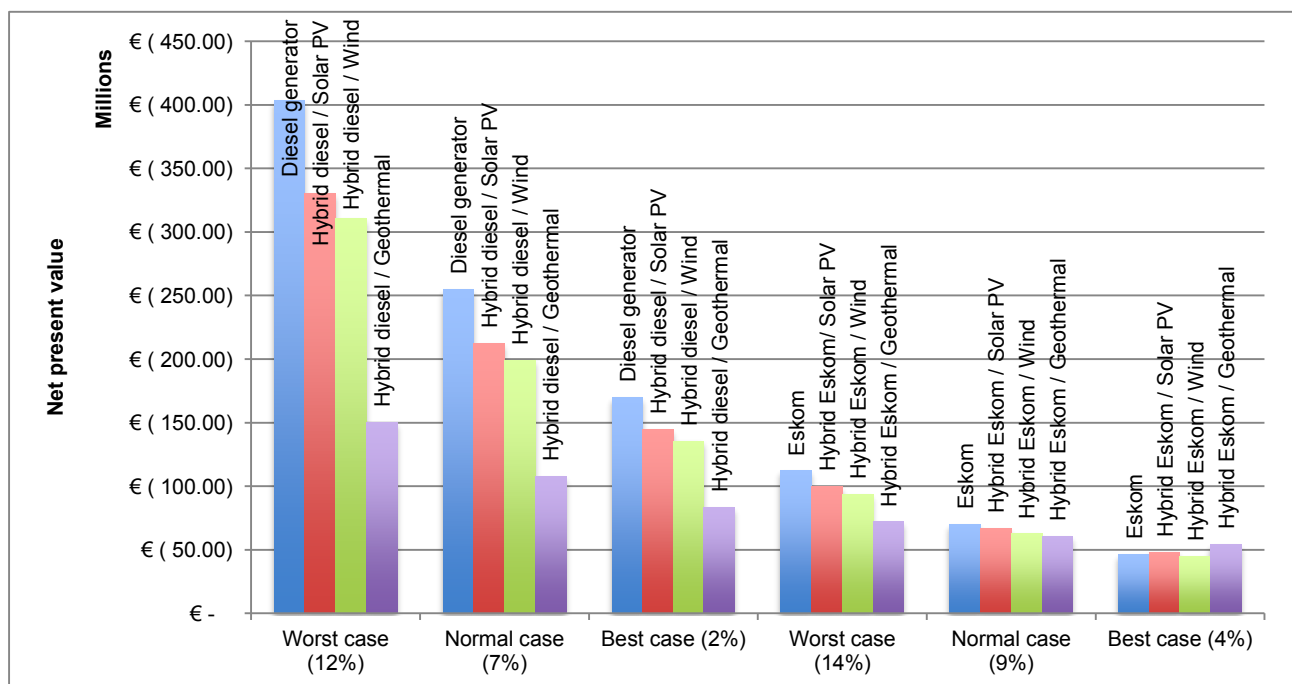


Figure 5.12: Effect of diesel price and Eskom tariff prediction on net present value

5.4.3 Implications of a CO₂ tax

The possible impact of the implementation of a CO₂ tax is again illustrated with the criteria of levelised costs and net present value, as the effect is the biggest. A comparison can be seen in Figure 5.13 and 5.14. The overall ranking of all electricity sources was not affected. As stated in the last draft of the carbon tax bill, the effective carbon tax rate will

vary between €0,43 (ZAR6) and €3,44 (ZAR48) per ton CO₂. In case Eskom will not be affected, it will stay as stated under “no tax”. Consequently, for illustration purposes of this study, the best and worst case was calculated with an annual increase of 10%. Eskom was included, as it is not certain yet how it is going to be affected (Mbadlanyana, 2013; The Carbon Report, 2015).

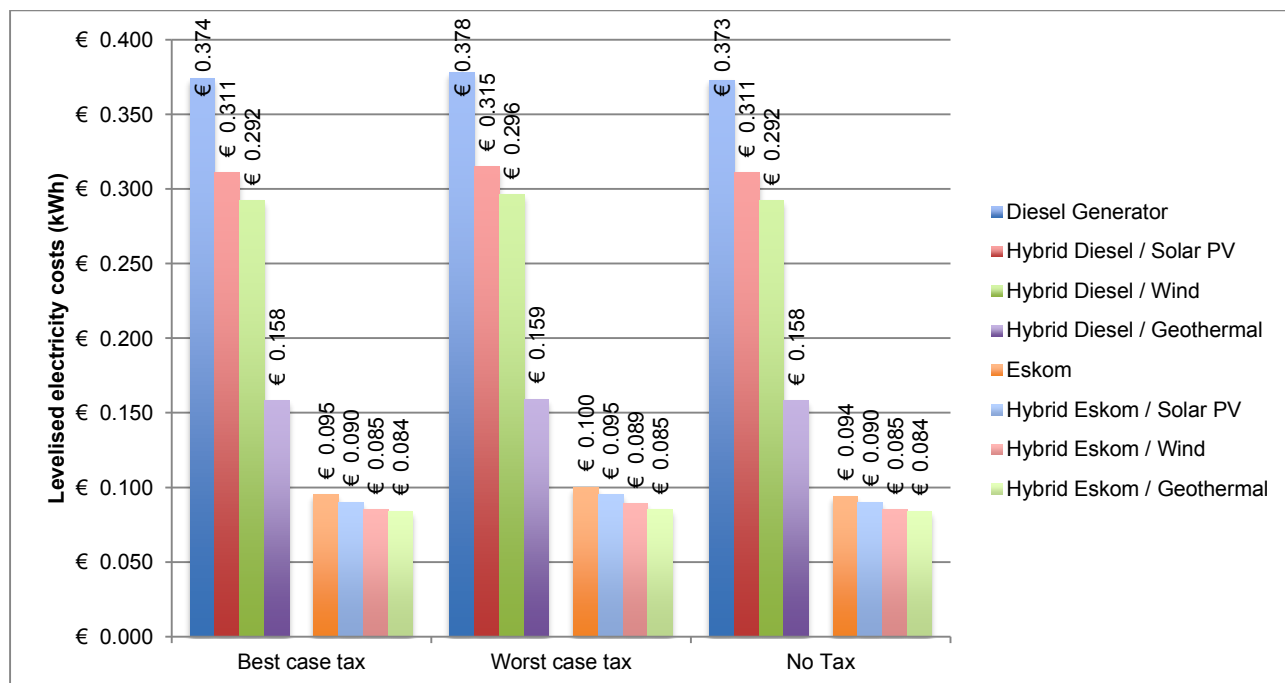


Figure 5.13: Effect of CO₂ tax on levelised electricity costs

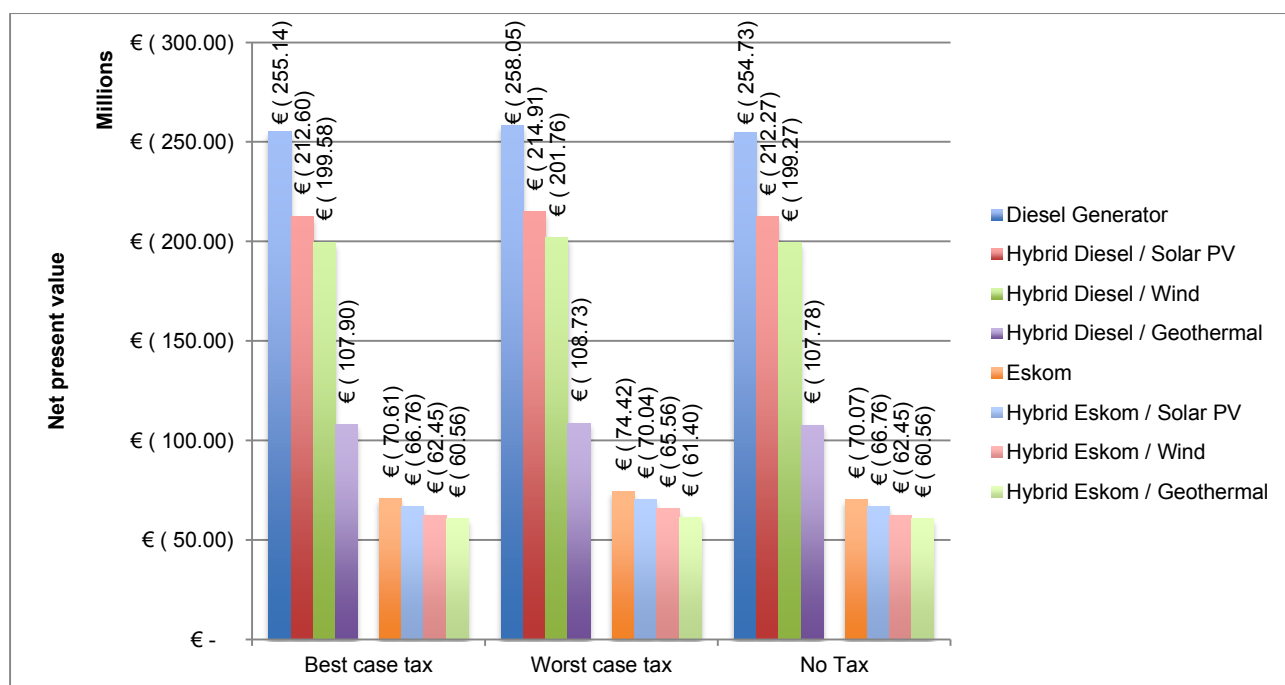


Figure 5.14: Effect of CO₂ tax on net present value

5.5 Conclusion

The discussion in this chapter is based on the results of chapter 3 and 4, which selected the MAVT method as the most appropriate research framework and revealed the criteria that South African mining corporations used to evaluate the selected electricity sources. The purpose of this chapter was, first, to state and back up the real time data gained through the primary research process. The analysis and evaluation of the selected sources, which was conducted in cooperation with mining and energy companies operating in South Africa, is also discussed.

The main results of the adapted MAVT model showed that the hybrid versions with solar PV and on-shore wind were favourable in comparison to diesel generators or the Eskom grid-connection alone. The advantages of diesel generators were significantly greater than those of Eskom grid-connection. As renewable sources are steadily advancing and the currently used sources are becoming ever more expensive, the trend will shift further towards renewables. In combining the macroeconomic influences with the MAVT results of this chapter, hybrid solar versions were identified as having the greatest potential. Hybrid wind solutions were in second place, as good wind conditions occur only in coastal regions where there are fewer mining activities. Geothermal hybrid versions were selected as least favourable owing to a low service infrastructure and high initial investment costs.

The performance matrixes have indicated that the usage of renewable hybrid versions contributes to long-term success, but requires an initial shift from operational to capital expenses. Considering the overall rankings and specifically the levelised costs, renewables are already profitable with a 5-year lifespan and diesel generators. However, for Eskom hybrid versions, only wind is profitable over a 10-year span and the rest over 20 years.

This chapter provides information for use by the management of mining corporations in South Africa. The aim is to illustrate how the relatively new opportunity of renewables could perform from the perspective of mining corporations while at the same time considering the external influences. The following chapter provides a summary of the findings of this study.

Chapter 6 Summary of findings and Conclusion

6.1 Contribution

To investigate a possible fit regarding how renewables can perform in respect to the specific characteristics of mining operations in South Africa

This research investigates a possible fit regarding how renewables can perform in respect to the characteristics of mining operations in South Africa. The purpose of the study was to provide information to the management of mining corporations regarding a possible fit to their specific requirements. The research process was conducted in three phases, which provides the structure for the conclusions of this chapter. The first phase investigated the influences on the market of renewables for mining operations in South Africa. In the second phase, the MAVT was selected as the best research approach. In addition, previous applications of MCDA methods to similar cases were investigated to contribute to the foundation of this research. During the last phase, the newly created knowledge about the external and internal environment was combined. The MAVT was adapted specifically for this study, implemented and results were realised, as summarised in this chapter.

The outcome of the research contributes to two fields of knowledge. On the one hand, it has widened the boundaries of the MCDA field since no similar adaptation in energy planning could be found in the review of previous studies (section 3.4.3 and 5.2.1). The main contribution is to the field of energy planning of mining corporations, operating within the borders of South Africa. The research was of an exploratory, qualitative nature owing to the relatively new approach of analysing a possible fit of renewables to mining operations in South Africa. Consequently the fieldwork consisted of smaller samples of four mining corporations and five energy companies with detailed interview sessions. The following sections provide a summary of the results. As already stated in the introduction, the results cannot be generalized to all mining operations as characteristics of mines might differ, rather should it provide guiding information to the opportunity of renewable energy sources.

6.2 Summary of findings: Phase one

Analyse the influences on the market of renewable electricity sources for mining corporations in South Africa

6.2.1 A possible fit of renewable sources to mining operations

Determine a possible fit of renewable sources to mining operations.

The current economic situation for most mines in South Africa is extremely challenging, especially with significantly increasing electricity prices and labour unrest and strikes. Power rarely constitutes less than 10% of mining operating costs and often exceeds 25% (Banerjee et al., 2015). As discussed in section 2.2, especially mines that work underground and are specialized in minerals like aluminium are more affected than a surface coal mine. Several renewable sources have half the levelised costs of diesel generators and are close to parity with Eskom (see Table 2.2). This is without including forecasted future price changes, which are also in favour of renewables. However, in the case of own investment, the disadvantage of renewables is the high initial capital expense, over current operational expenses. Therefore, it can be seen as an investment for long-term success.

The risk factor of high initial capital expenses, combined with limited global experience, necessitates the further research for decision-making leaders of mining corporations. The global renewable energy market only started to evolve with the first project in 2010, with the first and so far only project in South Africa, being realized in 2012 (see Table 2.1). In this field, Chile is the world leader, hosting more than half of the identified global projects, and the majority being grid-connected with sizes of up to 115 MW. All other global projects are off-grid and extend up to the size of 6,7 MW.

To evaluate a possible fit of renewable sources, it was crucial to analyse the electricity usage patterns of mining operations. As discussed in section 2.2, most mines have a relatively constant baseload consumption. Therefore, considering the intermittency of most renewable sources, it is only possible to use them in a hybrid version. If the mine is not grid-connected, a hybrid version with the currently used diesel generator was identified as most promising, as storage facilities are still too expensive.

6.2.2 Current attractiveness of different renewable sources

Assess and select the most attractive current and renewable electricity sources

Section 2.3 investigated the attractiveness of renewable and current electricity sources for mining operations in South Africa. The renewable technology with the highest potential for the majority of mining corporations in South Africa is solar PV. Initial investment costs of solar PV are low in comparison to other renewable energy technologies besides wind power, but roughly three times the price of present sources. However, current levelised costs for solar PV are half the amount of diesel generators and close to parity with Eskom. The global experience in the solar PV market is the most highly established with 11 projects, which demonstrates the success of the model (see Table 2.1). The availability of the power source is also the best compared to the other renewable technologies. Furthermore, owing to the numerous companies situated in South Africa, the service infrastructure is well developed.

Wind energy was selected as the second best option. The disadvantage, in comparison to solar PV, is the lower availability of the power source, which decreases the potential for on-site realisations.

The third and last option selected for its potential was geothermal technology. Though the initial investment costs are high, the levelised costs are low. Disadvantages are that there is no experience with this technology within mining operations, service infrastructure is low and the technology is relatively new, especially in South Africa.

Owing to the electricity usage patterns of mining operations and the intermittency, especially of solar PV and wind, a hybrid version with current sources has to be used. The geothermal option is by far the highest capacity factor of up to 90% (see Table 2.2).

All other renewable energy technologies were evaluated as unsuitable at the current state of development. The initial investment costs for CSP and battery storage are too high. There is no experience and a low service infrastructure with biomass. A combination of low power source availability, little experience within mining operations, and a very young service infrastructure are the reasons for not selecting hydro power as an option.

To execute a project, the business model of self-generation was identified as the most promising, and can be realised through own investment or an independent power producer

(IPP) agreement. To focus on the evaluation of a possible fit of renewables to mining operations the model of own-investment was selected. A third party involvement would deviate from this goal.

6.2.3 Potential of different business models

Determine the potential of different business models.

The business model of self-generation was selected as the most attractive one in South Africa. The model entails the least actors, which simplifies the realisation process. As far as the regulatory framework is concerned, this option was the most feasible one as no additional organisations are involved or licences needed (see section 2.4). Wheeling options were not considered, as additional costs are up to 18% of the electricity price and levelised costs of renewables are close to parity with Eskom. The option of using an IPP is limited, especially for smaller, remote mines. Some of the reasons are the elevated risk factor of international institutions investing in South Africa, the risk that the mine as the only customer may close down, and limited global experience with renewable projects at mining operations (Reeves et al., 2015; Baker and McKenzie, 2013).

6.2.4 Additional influences on the market

Identify and evaluate additional influences on the market

To answer the fourth secondary objective (see Figure 2.1), additional influences were considered, even though they do not affect project realisation directly. The corporate development provides an indication of how the South African market of renewables is developing in the large energy user sector. The government and industrial energy-intensive users have started to take action, by announcing their efforts in public media. The government has created specific targets to become greener. The majority of members of the EIUG have started to implement energy efficiency and environmental protection programmes.

The planned South African CO₂ tax of €8,61 (ZAR120) with an actual effective impact of between €0,43 (ZAR6) and €3,44 (ZAR48) still involves a lot of controversy regarding the realisation. Eskom customers might be excluded of the tax. It is not sure yet if or when the tax will be implemented. In a case study by two large mining corporations operating in South Africa, it is reported that the tax will spur their current negative economic

development. However, the tax will add to the attractiveness of renewable sources to reduce CO₂ emissions (Forer et.al, 2014).

6.3 Summary of findings: Phase two

Asses and select the most suitable research approach

6.3.1 The selection of the most suitable research approach

Identify the most suitable research approach.

Assess the different methods of the selected research approach

In phase two, the main research objective was to use an existing strategic approach as a foundation to structure this study. The reason for this is that the existing theory and experience assist in considering all aspects of the field being investigated. Based on a detailed investigation, the MCDA approach was selected. The approach used the internal evaluation process, including evaluation criteria and preference functions, to analyse the different electricity sources selected in chapter 2 in the best way possible. After further investigations, the MAVT was selected as the method to be adapted and implemented. This method is the most detailed MCDA method, which would enable the research to produce the most comprehensive results. The advantage of this method is that it allows incorporation of the perspectives of mining corporations in the evaluation of a possible fit of renewables with regard to their specific requirements.

6.3.2 Previous adaptations to similar cases

Identify previous adaptations of the selected research approach to similar cases.

To gain a state-of-the-art overview, 26 MCDA approaches implemented in recent years, starting 2001, were investigated. To achieve greater insights, 13 of the selected approaches analysed only renewable electricity sources and the other 13 a mix of conventional and renewable sources. In addition, a list of criteria used in the approaches was drawn up. The information generated provided a solid foundation and backup knowledge for the interview sessions. However, no approach in energy planning viewed from a corporate, especially mining perspective, could be found globally. The majority were viewed from a governmental or general perspective. Furthermore, no approach in energy planning could be identified in South Africa.

6.4 Summary of findings: Phase three

Develop an MCDA adaptation to analyse and compare current to renewable electricity-generating sources for mining operations.

6.4.1 Evaluation criteria for mining corporations

Determine the criteria according to which mining corporations evaluate the selected electricity sources

The findings of this research have revealed, for the first time, how corporate entities, especially mining corporations, evaluate electricity sources. The majority of criteria used are similar to those used in previous adaptations, unrelated approaches; however, the business nature of mining corporations showed some differences. The business orientation includes considering possible future changes. New economic evaluation criteria were the prediction of fuel costs and initial investment.

Also connected to the business orientation are the added technological criteria of implementation period and service level. Business performance is affected during the implementation period, as the source is not contributing yet. The service level is especially important in emerging countries to ensure smooth operations. Lastly, two different social criteria were used. Corporate image, being one, is specific to corporations, for reasons like showing green leadership. The effect on the surrounding communities, being the other, is more specific to mines, as mining effects are usually of a more polluting nature.

6.4.2 Adaptation of the MCDA method

Adapt the MCDA method to assist mining corporations to select the best electricity source.

The adaptation is described in chapter 4 and the results are presented in chapter 5. The MAVT adaptation was based on the decision framework identified in chapter 2, which included an investigation of renewables to the usage requirements of mining operations, a selection of the most attractive renewable electricity sources and the most suitable business model. During the adaptation process, the mining respondents gave their input to develop the evaluation structure in order to analyse the selected sources from their perspective. The energy companies contributed their knowledge to fill the evaluation structure with the required data.

6.4.3 Analysis and comparison of current to renewable electricity sources for mining operations in South Africa

Analyse and compare current to renewable electricity sources.

The main results of the third research phase, which comprised the adaptation and implementation of the MAVT method, have shown that the hybrid versions with solar PV and on-shore wind are always favourable in comparison to diesel generators or Eskom grid-connection alone. The advantage, compared to diesel generators, is significantly higher than when compared to an Eskom grid-connection. As the development of renewable sources continues to advance and the currently used sources become more expensive, the trend will shift further towards renewables. In combining the influences on the market of chapter 2 with the MAVT results of chapter 5 of this study, hybrid solar PV versions are identified as having the greatest potential. Hybrid wind solutions are in second place as good wind conditions only occur in coastal regions where there are fewer mining activities. Geothermal hybrid versions were selected as least favourable owing to a low service infrastructure and high initial investment costs.

6.4.4 Sensitivity analysis

Investigate the sensitivity of the results to changes in key values of the methods.

The sensitivity analysis has again indicated that the usage of renewable hybrid versions contributes to long-term success, but requires an initial shift from operational to capital expenses. The planned lifespan of the source is the first variable alternated. Considering the overall rankings, and specifically the levelised costs, hybrid versions with diesel generators are already profitable over a five-year lifespan. For Eskom, however, the advantage of using renewables is still relatively small, which lowers the incentive of switching from operational to capital expenses. With Eskom hybrid versions, only wind is profitable over a 10-year span and the rest over 20 years.

The second variable alternated are the diesel price forecast and the Eskom tariff. The overall ranking for both sources was not affected. The diesel price was predicted to increase by 7%. The sensitivity analysis investigated an alternation of $\pm 5\%$. The effect on levelized costs is from best to worst case scenario 139% of the price. The usage of solar PV and wind reduces the sensitivity to 127% and with geothermal to 80%. The Eskom tariff was predicted to increase annually by 9%. Again, the sensitivity analysis investigated

an alternation of $\pm 5\%$. The difference from best case to worst case scenario is for Eskom alone a difference of 140% of the price. The use of solar PV and wind reduces the sensitivity to 105% and with geothermal to 25%.

The third variable manipulated was the possible influence of the planned CO₂ tax. As the exact ruling is not known yet, a best and worst case scenario based on a 20-year lifespan of €0,43 (ZAR6) and €3,44 (ZAR48) was investigated. The overall ranking of all sources was not affected. In case Eskom will be excluded the value without tax was used. The implementation of a CO₂ tax has an impact of less than €0,01 on all sources analysed.

6.5 Limitations of the study and opportunities for future research

Although this study aimed to make a significant contribution to the body of knowledge of how renewable electricity sources perform for mining operations, certain areas still need to be explored or expanded. Based on the outcomes of this research, the following limitations are noted and opportunities for future research on are outlined:

- The usage of only four mining corporations, with a total of 11 mining operations as the sample, is a limitation of this study. Over 20 corporations were contacted and four agreed to participate and provide detailed information. Indeed all four participating bodies had already been looking into the usage of renewables and were, therefore, interested in the outcome of the study. Numerous companies declined to participate, having the perception that renewables would not contribute to a better business performance, satisfying their baseload demands and arguing that electricity generation is not their core business.

Therefore, experience gained throughout the research process showed that the energy engineer was the most suitable person to participate in this study. He prepares the information for the management. The operational and financial managers were not competent to answer the questions, as electricity generation is not their field of expertise. Since the exploratory and qualitative aspects have been dealt with in this study, future research should validate the model and increase the sample, by including corporations that are not interested in looking into renewable electricity sources. In addition, several respondents stated that mining corporations are going to launch energy departments to manage the increased electricity costs more efficiently. This would generate a bigger scope for the model.

- The study targeted all types of mining corporations to participate and contribute to the research. The participating corporations differed in factors like corporation size, amount of electricity usage and resources mined. Therefore, aspects that influence the evaluation process, like financial resources and availability of experts, are dissimilar. Additional research could unify certain groups to create a better picture of the potential of different types of mining corporations to realise renewable energy projects.
- The research process was conducted with one respondent from each of the four participating mining corporations. It was assured that the respondents were part of the evaluation process of possible electricity sources. However, gaining the information from only one respondent can be a limitation as not all aspects might be considered. Future research should incorporate several perspectives, by including respondents from the strategic management team, the financial department and the engineering profession. This would further ensure that all aspects are considered in the model.
- The study focused on the realisation of renewable projects from the perspective of own investment. This was done because the mining corporation renewables market is still very young and it was necessary to keep the focus on the evaluation of electricity sources and, consequently, to maximise the learning process. The limitation here is that some mining corporations would prefer to realise a renewable energy project through a power purchase agreement to minimise the financial risk. Future research should incorporate and investigate the different financial constructs in South Africa.
- One limitation of using the MAVT method in the context of this study is the fact that the model is created on a pre-determined framework. The framework consisted of factors like the selected electricity sources and business model. Therefore, it is not always possible to use the adapted model for different electricity source, as the evaluation criteria might differ.
- Lastly, the study adapted the MCDA method based on a qualitative and exploratory approach, as this had not been done before. In addition, four different mining corporations participated to create a more generic and educational model. Future research should consider case studies, where the created model is implemented for specific mining operations. This would create a more detailed understanding of the

concept and a further real-time example for mining corporations to understand the opportunity.

6.6 Conclusion

The past and projected future economic situation of mining corporations operating in South Africa creates the opportunity for renewable electricity sources to contribute to their long-term success. The advantages would be greater independence from diesel and Eskom's electricity supply, lower electricity costs and reduced CO₂ emissions.

Although this study reveals that the long-term benefits are evident, several factors have to be overcome to increase the attractiveness of this opportunity. Firstly, electricity generation is not the core business of mining corporations; currently, the process to use new electricity technologies is lengthy and is often based on benchmarking. Secondly, the current economic situation with labour difficulties and decreasing commodity prices reduces the attractiveness of renewables, as the high initial investment costs would negatively affect their balance sheet.

Future research should investigate the option of third party (IPP) involvement, which would include the most attractive framework to realise a renewable project. Table 2.1 indicates that grid connected projects are preferred to be realized through an IPP, as the electricity demand is not reliant on one customer. The results, if positive, could contribute to lower the risk of involvement and, consequently, increase the attractiveness of this market. The IPP project realization would counter the problems of high fix costs, a negative effect on the balance sheet and electricity generation not being a mine's core business.

References

- ABENGOA SOLAR. 2015. Industrial installation of concentrating solar power in Chile. http://www.abengoasolar.com/web/en/nuestras_plantas/plantas_para_terceros/chile/index.html [accessed 31 January 2015].
- AECI. 2011. Green Gauge. http://www.aeci.co.za/green_gauge/introduction.html [accessed 7 April 2015].
- AFGAN, N.H., AND CARVALHO, M.G. 2002. Multi-criteria assessment of new and renewable energy power plants. *Energy*, vol. 27, no. 8. pp. 739–755.
- AHLFELDT, C. 2013. The localisation potential of photovoltaic (PV) and a strategy to support large scale roll-out in South Africa. South Africa: WWF, SAPVIA, Department of Trade and Industry, Pretoria.
- AHMAD, S., AND TAHAR, R.M. 2014. Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia. *Renewable Energy*, vol. 63. pp. 458–466.
- AIR LIQUIDE. 2014. Environment. <http://www.airliquide.com/en/environment.html>. [accessed 7 April 2015].
- ALTON, T., ARNDT, C., DAVIES, R., HARTLEY, F., MARKRELOV, K., THURLOW, J., AND UBOGU, D. 2014. Introducing carbon taxes in South Africa. *Applied Energy*, vol. 116, March. pp. 344–354.
- AMBROS, D. 2014. Project “zimbi”: PV/diesel hybrid power case study. Final report. Unterhaching: Cronimet Power Solutions GmbH.
- ANGLO OPERATIONS. 2014. Climate change and energy. <http://angloamerican.com/development/envs/climate-change-and-energy/approach.aspx> [accessed 7 April 2015].
- ANGLO PLATINUM. 2014. Energy. <http://www.angloplatinum.co.za/sus/mat/energy.asp> [accessed 7 April 2015].
- ANGLOGOLD ASHANTI. 2014. Sustainability. <http://www.anglogold.co.za/Sustainability/Archives.htm>. [accessed 7 April 2015].

- ARCELOMITTAL. 2014. Tackling climate change. <http://corporate.arcelormittal.com/corporate-responsibility/environment/climate-change-and-energy/approach> [accessed 7 April 2015].
- ASLANI, A. 2014. Private sector investment in renewable energy utilization: Strategic analysis of stakeholder perspectives in developing countries. *International Journal of Sustainable Energy*, vol. 33, no.1. pp. 112–124.
- ASSORE. 2014. Company profile. <http://www.assore.com> [accessed 7 April 2015].
- BAKER AND MCKENZIE. 2013. The future of clean energy in Africa. Final report. Chicago: Green Energy Pipeline.
- BANERJEE, G.S., ROMO, Z., MCMAHON, G., TOLEDANO, P., AND ROBINSON, P. 2015. The power of the mine: A transformative opportunity for sub-Saharan Africa. Final report. Washington D.C.: World Bank Group, ESMAP, Africa Region Sustainable Development.
- BAXTER, R. 2015. Presentation of Chamber position on Carbon Tax to the Davis Tax Committee. Johannesburg: Chamber of Mines of South Africa.
- BEUKMAN, H. 2015. Mineral sand resources. Presentation. Johannesburg: MSR.
- BHP BILLITON. 2014. Sustainability in action. <http://www.bhpbilliton.com/home/aboutus/sustainability/Pages/Sustainability-in-action.aspx> [accessed 7 April 2015].
- BOLE-RENTEL, T., AND BRUINSMA, D. 2013. The Bioenergy sector in South Africa. Den Haag: tbr Consulting, ECN, Bruinsma Solutions.
- BORAN, F.E., BORAN, K., AND MENLIK, T. 2012. The evaluation of renewable energy technologies for electricity generation in Turkey using intuitionistic Fuzzy TOPSIS. *Energy Sources, Part B: Economics, Planning, and Policy*, vol. 7, no. 1. pp. 81–90.
- BORAN, F.E., DIZDAR, E., TOKTAS, I., BORAN, K., ELDEM, C., AND ASAL, Ö. 2013. A multidimensional analysis of electricity generation options with different scenarios in Turkey. *Energy Sources, Part B: Economics, Planning, and Policy*, vol. 8, no. 1. pp. 44–55.

- BOUYSSOU, D., JACQUET-LAGREZE, E., PERNY, P., SLOWINSKI, R.,
VANDERPOOTEN, D., AND VINCKE, P. 2002. Aiding Decisions with Multiple
Criteria: Essays in Honor of Bernard Roy. Dordrecht: Kluwer Academic Publishers.
- BOYSE, F., CAUSEVIC, A., DUWE, E., AND ORTHOFER, M. 2014. Sunshine for mines:
Implementing renewable energy for off-grid operations. Washington, DC: Carbon
War Room.
- BRAND, B., AND MISSAOUI, R. 2014. Multi-criteria analysis of electricity generation mix
scenarios in Tunisia. *Renewable and Sustainable Energy Reviews*, vol. 39. pp.
251–261.
- BRANKER, K., PATHAK, M.J.M., AND PEARCE, J.M. 2011. A review of solar photovoltaic
levelized cost of electricity. *Renewable and Sustainable Energy Reviews*, vol. 15
no. 9 pp. 4470–4482.
- BRODSKY, S., CURNOW, P., FEVRE, M., GHANNAM, M., NASROLLAH, K., AND
O'BRIEN, J.P. 2013. The future of clean energy in Africa. Chicago: Baker &
McKenzie.
- CAMERON, E., AND GREEN, M. 2012. Making Sense of Change Management: A
Complete Guide to the Models, Tools and Techniques of Organizational Change.
3rd edn. Great Britain, Kogan Page Limited.
- CAVALLARO, F. 2009. Multi-criteria decision aid to assess concentrated solar thermal
technologies. *Renewable Energy*, vol. 34, no. 7. pp. 1678–1685.
- CETINDAMAR, D., DAIM, T.D., BEYHAN, B., AND BASOGLU, N. 2013. Strategic
Planning Decisions in the High Tech Industry. London, Springer Verlag.
- CHAMBER OF MINES. 2014. Facts & Figures 2014. Johannesburg: Chamber of Mines of
South Africa.
- CHANG, C.T. 2011. Multi-choice goal programming with utility functions. *European Journal
of Operational Research*, vol. 215, no. 2. pp. 439–445.
- CHATZIMOURATIDISA, A.I., AND PILAVACHI, P.A. 2008. Multicriteria evaluation of
power plants impact on the living standard using the analytic hierarchy process.
Energy Policy, vol. 36, no. 3. pp. 1074–1089.

- CHATZIMOURATIDISA, A.I., AND PILAVACHI, P.A. 2009a. Sensitivity analysis of technological, economic and sustainability evaluation of power plants using the analytic hierarchy process. *Energy Policy*, vol. 37, no. 3. pp. 788–798.
- CHATZIMOURATIDISA, A.I., AND PILAVACHI, P.A. 2009b. Technological, economic and sustainability evaluation of power plants using the analytic hierarchy process. *Energy Policy*, vol. 37, no. 3. pp. 778–787.
- CHISLETT, M. 2014. Cleaner energy at stable prices: The value proposition of solar for mines. Interview. Toronto, Energy and Mines.
- CNN MONEY. 2015a. Exchange rate Euro-Dollar. <http://money.cnn.com/data/currencies/>. [accessed 13 July 2015].
- CNN MONEY. 2015b. Exchange rate Euro-South African Rand. <http://money.cnn.com/data/currencies/>. [accessed 13 July 2015].
- COLUMBUS STAINLESS. 2014. Environment. <http://www.columbusstainless.co.za/corporate-responsibility/environment.html> [accessed 7 April 2015].
- CONSOL. 2014. Environment campaign. <http://www.consol.co.za/irj/go/km/docs/site/pages/default.html> [accessed 7 April 2015].
- COOKIE, R., CRIPPS, A., IRWIN, A., AND KOLOKOTRONI, M. 2007. Alternative energy technologies in buildings: Stakeholder perception. *Renewable Energy*, vol. 32, no. 14. pp. 2320–2333.
- CREAMER, T. 2012. Big users urge hard line on Eskom costs, as utility delays tariff submission. *Mining Weekly*, 31 August. <http://www.miningweekly.com/article/big-users-urge-hard-line-on-eskom-costs-as-utility-delays-tariff-submission-2012-08-31> [accessed 7 April 2015].
- CRESPO, P. 2015a. Avoiding escalating power costs and supply disruptions is critical for mining, says Anglo American Energy Leader. London: Energy and Mines.
- CRESPO, P. 2015b. Mining leaders wants to understand the cost-effectiveness of renewables. London: Energy and Mines.

- CRESPO, T. 2015c. Despite barriers to adopting, costs pressure driving renewed mining interest in renewable energy. Toronto: Energy and Mines.
- CRESWELL, W.C. 2014. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. 4th ed. California: SAGE publications.
- CRISTOBAL, J.R.S. 2011a. A multi criteria data envelopment analysis model to evaluate the efficiency of the renewable energy technologies. *Renewable Energy*, vol. 36, no. 10. pp. 2742–2746.
- CRISTOBAL, J.R.S. 2011b. Multi-criteria decision-making in the selection of a renewable energy project in Spain: The Vikor method. *Renewable Energy*, vol. 36, no. 2. pp. 498–502.
- CRONIMET POWER SOLUTIONS. 2015. Project Thabazimbi chromium mine. <http://www.crm-ps.com/en/thabazimbi.php> [accessed 7 April 2015].
- CUMMINS, J., KNIGHT, A., AND TAYLOR, L. 2008. Consumer attitudes and awareness of green issues and energy. <http://www.ofgem.gov.uk/Sustainability/Cp/CF/Documents1/environmentalresearch> [accessed 7 April 2015].
- DATTA, A., RAY, A., BHATTACHARYA, G., AND SAHA, H. 2011. Green energy sources (GES) selection based on multi-criteria decision analysis (MCDA). *International Journal of Energy Sector Management*, vol. 5, no. 2. pp. 271–286.
- DAY, B. 2014. Head of Advocacy. Cennergi. Stellenbosch: Personal Interview, [23 May].
- DE BEER, A.J. 2000. The development of a generic model for strategic planning for small and medium manufacturing enterprises in a turbulent environment. MBA research assignment, Stellenbosch University, South Africa.
- DELOITTE. 2012. The economic impact of electricity price: Increases on various sectors of the South African economy. Johannesburg: Deloitte & Touche.
- DE RUS, G. 2010. Introduction to Cost-benefit Analysis Looking for Reasonable Shortcuts. Cheltenham, UK, Edward Elgar Publishing.
- DEA. 2015. Department of Environmental Affairs, Republic of South Africa. <https://www.environment.gov.za> [accessed 7 April 2015].

- DHAWAN, R. 2015. Carbon tax in the mining sector. Business Media Live.
<http://www.businessmedialive.co.za/the-distributional-impacts-of-a-carbon-tax-in-the-mining-sector/>. [accessed 25 November 2015].
- DIAKOULAKI, D., AND KARANGELIS, F. 2007. Multi-criteria decision analysis and cost-benefit analysis of alternative scenarios for the power generation sector in Greece. *Renewable and Sustainable Energy Reviews*, vol. 11, no. 4. pp. 716–727.
- DICKENS, A., SINGH, C., BOSSET, P., MITCHELL, V., COSGROVE, J., MCLOUGHLIN, S., AND CUADRADO, P. 2014. *Energy storage: Power to the people*. London: HSBC Global Research.
- DOE. 2013. *Integrated Resource Plan for Electricity (IRP) 2010–2030*. Johannesburg: Department of Energy, Republic of South Africa.
- DOE. 2015a. Department of Energy, Republic of South Africa. <http://www.doe-irp.co.za> [accessed 6 April 2015].
- DOE. 2015b. Global energy storage database. U.S. Department of Energy. www.sandia.gov/ess/database [accessed 2 April 2015].
- DTI. 2015. *The wind energy industry localisation roadmap in support of large-scale roll-out in South Africa*. Johannesburg: Department of Trade and Industry, Republic of South Africa.
- E-CL. 2015. E-CL and Quiborax to build solar PV plant. http://www.e-cl.cl/prontus_ecl/site/artic/20130705/pags/20130705115312.php [accessed 30 January 2015].
- EDWARDS, W., MILES, R.F., AND VON WINTERFELDT, D. 2007. *Advances in Decision Analysis: From Foundations to Applications*. Cambridge, Cambridge University Press.
- EIA. 2013. *Updated capital cost estimates for utility scale electricity generating plants*. Washington: U.S. Energy Administration Information, Department of Energy.
- EIUG (ENERGY INTENSIVE USER GROUP OF SOUTHERN AFRICA). 2014a. Members of the group. <http://www.eiug.org.za>. [accessed 7 April 2015].

- EIUG (ENERGY INTENSIVE USER GROUP OF SOUTHERN AFRICA). 2014b. Electricity cost as a percentage of annual expenditure. <http://www.eiug.org.za/about/membership/> [accessed 27 December 2014].
- EIUG (ENERGY INTENSIVE USER GROUP OF SOUTHERN AFRICA). 2015. Electricity cost as a percentage of annual expenditure. <http://www.eiug.org.za/about/membership/> [accessed 11 Jun 2015].
- ELLIOTT, M. 2014. Business risks facing mining and metals. London: Ernst & Young Global Mining & Metals Center.
- ELIASSON, B., AND LEE, Y.Y. 2003. Integrated Assessment of Sustainable Energy Systems in China. Dordrecht: Kluwer Academic Publisher Group.
- ENERCON. 2015. Windenergieanlagen. <http://www.enercon.de/de-De/windenergieanlagen.htm> [accessed 30 January 2015].
- ENERGY AND MINES. 2015. Introduction to renewable energy with mining operations. <http://energyandmines.com> [accessed 7 March 2015].
- ERTAY, T., KAHRAMAN, C., AND KAYA, I. 2013. Evaluation of renewable energy alternatives using MACBETH and fuzzy AHP multi criteria methods: The case of Turkey. Technological and Economic Development of Economy, vol. 19, no. 1. pp. 38–62.
- ESKOM. 2010. The energy efficiency series: Towards an energy efficiency mining sector. Johannesburg: Eskom Demand Side Management Department.
- ESKOM. 2013. Map of Eskom power stations. http://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Pages/Map_Of_Eskom_Power_Stations.aspx [accessed 4 April 2015].
- ESKOM. 2014. Environmental management. http://financialresults.co.za/2012/eskom_ar2012/fact-sheets/013.php. [accessed 4 April 2015].
- ESKOM. 2015a. Climate change. http://financialresults.co.za/2012/eskom_ar2012/fact-sheets/006.php#carbon [accessed 14 Jul 2015].
- ESKOM. 2015b. Tariff and charges. http://www.eskom.co.za/CustomerCare/TariffsAndCharges/Pages/Tariffs_And_Charges.aspx [accessed 13 Jun 2015].

- ESKOM. 2015c. Loadshedding. <http://loadshedding.eskom.co.za/LoadShedding/Index> [accessed 4 April 2015].
- ESKOM. 2015d. Tariff & charges booklet 2014/2015. Johannesburg: Eskom.
- ESKOM. 2015e. Company information. http://www.eskom.co.za/OurCompany/CompanyInformation/Pages/Company_Information_1.aspx [accessed 10 Jun 2015].
- ESKOM. 2015f. Transmission Development Plan 2015–2024. Johannesburg: Eskom.
- ESKOM. 2015g. Schedule of standard prices for Eskom tariffs 2016. Johannesburg: Eskom.
- ETH ZÜRICH SUSTEC. 2014. Derisking renewable energy investment NAMA finance case study exercise. New York: United Nations Development Program.
- EVRAZ. 2014. Social responsibility. <http://www.evrazhighveld.co.za/social.asp> [accessed 7 April 2015].
- EXXARO. 2014. Environment. http://www.exxaro.com/?page_id=324. [accessed 7 April 2015].
- FERRETTI, V., BOTTERO, M., AND MONDINI, G. 2014. Decision-making and cultural heritage: An application of the Multi-Attribute Value Theory for the reuse of historical buildings. *Journal of Cultural Heritage*, vol. 15, no. 6. pp. 644–655.
- FICHTNER. 2010. Technology assessment of CSP technologies for a site specific project in South Africa, final report. Johannesburg: The World Bank & ESMAP.
- FIRST SOLAR. 2015. Rio Tinto's project. <http://www.firstsolar.com/en/about-us/projects> [accessed 30 January 2015].
- FITZROY, P., HULBERT, J.M., AND GHOBADIAN, A. 2012. Strategic management: The challenge of creating value. 2nd edition. New York: Routledge.
- FORER, G., WARREN, B., O'FLYNN, B., ELLIOTT, M., MITCHELL, P. & DOWNHAM, L. 2014. Mining; The growing role of renewable energy. London: Ernst & Young.
- FOUCHÉ, N. 2013. Palabora mining company: The effect of power tariff increases. Management presentation. Phalaborwa: Palabora Mining Company.

- FRAUNHOFER ISE. 2013. Levelized cost of electricity: Renewable energy technologies. Freiburg: Fraunhofer Institute for Solar Energy Systems.
- FROST, F.A. 1995. The use of stakeholder analysis to understand ethical and moral issues in the primary resource sector. *Journal of Business Ethics*, vol. 14, no. 8. pp. 653–661.
- GALAXY RESOURCES. 2015. Mt Cattlin mining location. http://www.galaxyresources.com.au/pro_raven_mt_cattlin.shtml [accessed 31 January 2015].
- GAN, K.T., SHEK, J.H.K. AND MUELER, M.A. 2015. Hybrid wind–photovoltaic–diesel–battery system sizing tool development using empirical approach, life-cycle cost and performance analysis: A case study in Scotland. *Energy Conversion and Management*, vol. 106, pp. 479-494.
- GAUCHÉ, P., BRENT, A., AND VON BACKSTRÖM, T.W. 2014. Concentrating solar power: Improving electricity cost and security of supply, and other economic benefits. *Development Southern Africa*, vol. 31 no. 5 pp. 692–710.
- GEA. 2013. Geothermal power: International market overview. Washington D.C.: Geothermal Energy Association.
- GELDERMANN, J., AND SCHÖBEL, A. 2011. On the similarities of some multi-criteria decision analysis methods. *Journal of Multi-Criteria Decision Analysis*, vol. 18, no. 3-4. pp. 219–230.
- GETS, A., AND MHLANGA, R. 2013. Powering the future: Renewable energy roll-out in South Africa. Johannesburg: Greenpeace South Africa.
- GIELEN, D. 2012. Power sector costing study. Abu Dhabi: International Renewable Energy Agency.
- GIZ. 2014. Alternative energy in mining. Pretoria: German Cooperation; Deutsche Gesellschaft für Internationale Zusammenarbeit; South African Institute of International Affairs.

- GLENCORE. 2014. Sustainability. <http://www.glencorexstrata.com/sustainability/sustainability-reports/glencore-xstrata/2012/2012-sustainability-report> [accessed 7 April 2015].
- GLENCORE. 2015. Powering a mine on wind. <http://www.glencore.com/sustainability/case-studies/p/powering-a-mine-on-wind> [accessed 1 February 2015].
- GLOBAL DATA. 2014. Diesel generator market – global market size, equipment share and competitive analysis to 2020. London: Global Data Research Institute.
- GOH, H.H., LEE, S.W., CHUA, Q.S., GOH, K.C., KOK, B.C., AND TEO, K.T.K. 2014. Renewable energy project management, challenges and risk. *Renewable and Sustainable Energy Reviews*, vol. 38. pp. 917–932.
- GOLD FIELDS. 2014. Sustainability. http://www.goldfields.co.za/leadership_main.php [accessed 7 April 2015].
- GOVENDER, S. 2008. Energy saving mechanisms in the mining industry: A case study of switching off non-essential power. MBA thesis, Stellenbosch University, South Africa.
- GRANT, R.M., AND JORDAN, J. 2012. *Foundations of strategy*. West Sussex: John Wiley & Sons Ltd.
- GRIST, J. 2014. Climate change & sustainability service. Ernst & Young. Cape Town: Personal Interview, [28 July].
- HAGUE, P.N., AND JACKSON, P. 1995. *Do Your Own Market Research*. London, Kogan Page.
- HARMONY GOLD. 2014. Environment. <http://www.harmony.co.za/sustainability/environment> [accessed 7 April 2015].
- HAW, H. 2013. Overview of solar PV in South Africa. Cape Town: SAPVIA.
- HEO, E., KIM, J., AND BOO, K. 2010. Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP. *Renewable and Sustainable Energy Reviews*, vol. 14, no. 8. pp. 2214–2220.

- HINKLEY, J., CURTIN, B., HAYWARD, J., WONHAS, A., BOYD, R., GRIMA, C., TADROS, A., HALL, R., NAICKER, K., AND MIKHAIL, A. 2011. Concentrating solar power-drivers and opportunities for cost-competitive electricity. Victoria: CSIRO.
- HOUGH, J., THOMPSON, A.A., STRICKLAND, A.J., AND GAMBLE, J.E. 2011. Crafting and executing strategy. 2nd edition. Berkshire: McGraw-Hill.
- IEA. 2011. Geothermal heat and power roadmap. Paris: International Energy Agency.
- IEA. 2014. Africa energy outlook: A focus on energy prospects in Sub-Saharan Africa. Paris: International Energy Agency.
- IMF. 2014. World economic outlook. Washington D.C.: International Monetary Fund.
- IMPLATS. 2014. Our sustainability policy. <http://www.implats.co.za/implats/our-policy.asp> [accessed 7 April 2015].
- IRENA. 2012. Biomass for power generation. Abu Dhabi: International Renewable Energy Agency.
- IRENA. 2013a. Hybrid power systems. Abu Dhabi: International Renewable Energy Agency.
- IRENA. 2013b. Renewable Energy and Jobs. Abu Dhabi: International Renewable Energy Agency.
- IRENA. 2014a. Analysis of Infrastructure for Renewable Power in Southern Africa. Abu Dhabi: International Renewable Energy Agency.
- IRENA. 2014b. Renewable power generation costs in 2014. Abu Dhabi: International Renewable Energy Agency.
- IRENA. 2014c. Estimating the renewable energy potential in Africa: A GIS approach. Bonn: International Renewable Energy Agency.
- IRENA. 2015a. Renewable power generation costs in 2014. Bonn: International Renewable Energy Agency.
- IRENA. 2015b. Battery storage for renewables: Market status and technology outlook. Bonn: International Renewable Energy Agency.

- IRENA. 2015c. Africa power sector: Planning and prospects for renewable energy. Bonn: International Renewable Energy Agency.
- ISHIZAKA, A., AND NEMERY, P. 2013. Multi-criteria Decision Analysis. United Kingdom: John Wiley & Sons.
- JACOBSON, N., WYDER, J., FRANKLIN, S., AND McCracken, P. 2013. Data collection of diesel generators in South Australia. Canberra: IT Power Australia.
- JAKHOTIYA, G.P. 2013. Strategic Planning, Execution, and Measurement (SPEM). Boca Raton, Taylor & Francis Group.
- JAMASMIE, C. 2014. Anglo American considers closing platinum mines in South Africa. Mining. <http://www.mining.com/anglo-american-considers-closing-platinum-mines-in-s-africa-98146/> [accessed 6 April 2015].
- JONGENS, A.W.D. 2007. Environmental noise impact assessment for scoping purposes into the establishment of a wind energy facility along the West Coast, north of the Olifants River mouth. Cape Town: Savannah Environmental (Pty) Ltd.
- JUDD, E. 2014a. Positioning mines to meet the mining industry's energy needs. Toronto: Energy and Mines.
- JUDD, E. 2014b. Sincerity and patience required for renewables in mining sector. Toronto: Energy and Mines.
- JUNG, J., AND TYNER, W.E. 2014. Economic and policy analysis for solar PV systems in India. Energy Policy, vol. 74. pp. 123–133.
- KAGEL, A., BATES, D., AND GAWELL, K. 2007. A guide to geothermal energy and environment. Washington: Geothermal Energy Association.
- KAPLAN, S., AND NORTON, D.P. 1992. The balanced scorecard – measures that drive performance. Harvard Business Review. vol. 70, no. 1. pp 71-79.
- KAYA, T., AND KAHRAMAN, C. 2010. Multi criteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul. (Report). Energy, vol. 35, no. 6. pp. 2517–2527.

- KEENEY, R.L. 1992. Value-Focused Thinking: A Path to Creative Decisionmaking. Cambridge, MA: Harvard University Press.
- KEENEY, R.L. 1996. Value-focused thinking: Identifying decision opportunities and creating alternatives. *European Journal of Operational Research*, vol. 92, no. 3. pp. 537–549.
- KHATIB, H. 2008. Economic evaluation of projects in the electricity supply industry. London: The Institute of Electrical Engineering.
- KING, W., AND CLELAND, D. 1987. Strategic Planning and Management Handbook. New York, NY, Van Nostrand Reinhold.
- KLEIN, S.J.W., AND WHALLEY, S. 2015. Comparing the sustainability of U.S. electricity options through multi-criteria decision analysis. *Energy Policy*, vol. 79 pp. 127–149.
- KLUNNE, W.J. 2012. Current status and future developments of small and micro hydro in Southern Africa. *Journal of Energy in Southern Africa*. Vol. 24 no. 3 pp. 14–25.
- KOHLER, M. 2014. Differential electricity pricing and energy efficiency in South Africa. *Energy*, vol. 64 no. 1 pp. 524–532.
- KOTZE, C. 2014. Platinum first as fuel cells power rural homes in Free State. *Mining Weekly*, August 5. <http://www.miningweekly.com/article/platinum-fuel-cell-successfully-used-to-power-rural-households-2014-08-05> [accessed 22 January 2016].
- KUMAR, V., AAKER, D.A., AND DAY, G.S. 2002. Essentials of Marketing Research. New York, NY, John Wiley & Sons.
- KUSAKANA, K. 2014. A survey of innovative technologies increasing the viability of micro-hydro power as a cost effective rural electrification option in South Africa. *Renewable and Sustainable Energy Reviews*, vol. 37 no. 370–379.
- LAZARD. 2014. Levelized cost energy analysis – version 8.0. New York: Lazard Asset Management.
- LEE, A.H.I., HUNG, M., KANG, H., AND PEARN, W.L. 2012. A wind turbine evaluation model under a multi-criteria decision-making environment. (Report). *Energy Conversion and Management*, vol. 64. pp. 289–300.

- LERRO, A. 2011. A stakeholder-based perspective in the value impact assessment of the project “Valuing intangible assets in Scottish renewable SMEs”. *Measuring Business Excellence*, vol. 15, no. 3. pp. 3–15.
- LEVESQUE, M., MILLAR, D., AND PARASZCZAK, J. 2014. Energy and mining. *Journal of Cleaner Production*, vol. 84 pp. 233-255.
- LINARD, K.L., AND YOON, J. 2000. The dynamics of organizational performance development of a dynamic balanced scorecard. *Proceedings of the 1st international conference on systems thinking in management*, Geelong, Australia, 8-10, November.
- LINKOV, I., AND MOBERG, E. 2012. *Multi-criteria decision analysis: Environmental applications and case studies*. London: Taylor & Francis Group.
- LOKEN, E. 2007. *Multi-criteria planning of local energy systems with multiple energy carriers*. Doctoral thesis, Norwegian University of Science and Technology, Norway.
- LONMIN. 2014. *Sustainable Development Report*. <http://sd-report.lonmin.com/2012/people-planet-profit/planet> [accessed 7 April 2015].
- MAASDAM, R. 2015. *Energy crisis – The case of South Africa*. Johannesburg: Rabobank Economic Research Department.
- MAKE CONSULTING. 2013. *Global wind turbine trends 2012: Lowering the levelized cost of electricity*. Aahhus: MAKE Consulting.
- MAMLOOK, R., AKASH, B.A., AND MOHSEN, M.S. 2001. A neuro-fuzzy program approach for evaluating electric power generation systems. *Energy*, vol. 26, no. 6. pp. 619–632.
- MAMMATT, J., VAN DER WALT, C., MANDY, K., ERASMUS, L., AND ISAACS, K. 2011. *The case against introducing a carbon tax in South Africa*. Cape Town: PriceWaterhouseCoopers.
- MASTERS, G.M. 2013. *Renewable and Efficient Electric Power Systems*. 2nd ed. New Jersey: John Wiley & Sons.
- MATEK, B., AND GAWELL, K. 2014. *The economic costs and benefits of geothermal power*. Bochum: Geothermal Energy Association.

- MATEO, J.R.S.C. 2012. Multi Criteria Analysis in the Renewable Energy Industry. London, Springer Verlag.
- MATHABA, T., XIA, X., AND ZHANG, J. 2014. Analysing the economic benefit of electricity price forecast in industrial load scheduling. *Electric Power Systems Research*, vol. 116 pp. 158-165.
- MATHEWS, E.H. 2005. Implementation of DSM strategies at the Kopanang Mine. *Journal of Energy in Southern Africa*, vol. 16, no. 2. pp. 32-37.
- MAXIM, A. 2014. Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis. *Energy Policy*, vol. 65. pp. 284–297.
- MBADLANYANA, T. 2013. The political economy of carbon tax in South Africa. *Africa Insight*, vol. 43, no. 1. pp. 77–90.
- METRIC CONVERSION. 2015. Metric tons to ounces. <http://www.metric-conversions.org/weight/metric-tons-to-ounces.htm> [accessed 1 December 2015].
- MONDI GROUP. 2014. Sustainable development. <http://sd-report.mondigroup.com/2012/download-manager> [accessed 7 April 2015].
- MOSTERT, M. 2014. A quantitative method for selecting renewable energy projects in the mining industry based on sustainability. Master's thesis. Johannesburg: University of the Witwatersrand.
- NATIONAL TREASURY OF SOUTH AFRICA. 2015. Publication of the Draft Carbon Tax Bill for public comment. Pretoria: Department of National Treasury of South Africa.
- NEWTON, N. 2010. The use of semi-structured interviews in qualitative research: Strengths and weaknesses. http://www.academia.edu/1561689/The_use_of_semi-structured_interviews_in_qualitative_research_strengths_and_weaknesses [accessed 24 May 2014].
- NGUGI, P.K. 2012. What does geothermal cost? – the Kenya experience. El Salvador: United Nations University.
- NICOLAS, F. 2014. Africa-focused miners positioned to embrace 100% renewable energy. *Mining Weekly*, 21 May. <http://www.miningweekly.com/article/africa-focused->

miners-positioned-to-embrace-100-renewable-energy-2014-05-21 [accessed 2 Jun 2015].

NREL. 2009. Land-use requirement of modern wind power plants in the United States. Denver: National Renewable Energy Laboratory.

NREL. 2013. Land use requirements for solar power plants in the United States. Denver: National Renewable Energy Laboratory.

NREL. 2015. Concentrating solar power projects in South Africa. Colorado: National Renewable Energy Laboratory.

NUMBI, B.P., ZHANG, J., AND XIA, X. 2014. Optimal energy management for a jaw crushing process in deep mines. *Energy*, vol. 68, April. pp. 337–348.

ODENDAAL, N. 2015. Load-shedding a reality until 2023, says former Eskom adviser. *Mining Weekly*, 2 June. <http://www.miningweekly.com/article/load-shedding-a-reality-until-2023-says-former-eskom-adviser-2015-06-02>. [accessed 23 November 2015]

OECD. 2008. Environmental Outlook to 2030. Paris: OECD Publishing.

OECD. 2014. Economic Outlook no 95 – long term baseline projections. Paris: Organisation for Economic Co-operation and Development.

OPEC. 2014. World Oil Outlook. Vienna: Organization of the Petroleum Exporting Countries.

PATTERN ENERGY. 2015. El Arrayán wind. http://patternenergy.com/en/operations/projects/el_arrayan [accessed 30 January 2015].

PERSON, R. 2013. Balanced Scorecards & Operational Dashboards with Microsoft Excel. 2nd edn. Indianapolis, John Wiley & Sons.

PETTICREW, M., AND ROBERTS, H. 2006. Systematic Reviews in the Social Science: A Practical Guide. Oxford: Blackwell Publishing.

PEYPER, L. 2015. Can a carbon tax still fly as SA mining sinks? *Miningmx*, 13 August. http://www.miningmx.com/page/special_reports/mining-yearbook/mining-yearbook-

2015/1653564-Can-a-carbon-tax-still-fly-as-SA-mining-sinks#.VIXD_LSZa-I.
[accessed 25 November 2015].

PPC CEMENT. 2014. Sustainability. http://www.ppc.co.za/pages/environmental_energypolicy.cfm [accessed 7 April 2015].

PRESUTTI, W.D., AND MAWHINNEY, J.R. 2013. Understanding the Dynamics of the Value Chain. New York, Business Expert Press.

RAME ENERGY. 2014. Past projects. <http://www.rame-energy.com/operations/past-projects> [accessed 30 January 2015].

RAND WATER. 2014. Corporate responsibility. <http://www.randwater.co.za/CorporateResponsibility/Pages/Default.aspx> [accessed 7 April 2015].

REDDY, V., AND JORGENSEN, P. 2014. Managing greenhouse gas emissions in mining: Opinion. ReSource, vol. 16 no. 3 pp. 12–13.

REDEVIA. 2015. Mining location in Tanzania. <http://www.redaviasolar.com/mines> [accessed 31 January 2015].

REEVES, R., WHITTAKER, S., AND ELLINGHAUS, S.D. 2015. Conference Interview, 24 February. Johannesburg: Energy and Mining Summit.

REHMAN, S., ALAM, M., MEYER, J.P. AND AL-HADHRAMI, L.M. 2012. Feasibility study of a wind-pv-diesel hybrid power system for a village. Renewable Energy, vol. 38. pp. 258-268.

RENEWABLE ENERGY RESOURCE COOPERATION. 2014. Suriname solar project. <http://www.nerc.us/projects.htm> [accessed 30 January 2015].

REPUBLIC OF SOUTH AFRICA. 2013. Reducing greenhouse gas emissions and facilitating the transition to a green economy. Carbon Tax Policy Paper. Pretoria: National Treasury.

RIBEIRO, F., FERREIRA, P., AND ARAUJO, M. 2013. Evaluating future scenarios for the power generation sector using a multi-criteria decision analysis (MCDA) tool: The Portuguese case. Energy, vol. 52. pp. 126–136.

- RICHARDS BAY MINERALS. 2014. Environment. <http://www.rbm.co.za/ourapproach/environment.php> [accessed 7 April 2015].
- RINGLAND, G. 2006. Scenario Planning: Managing for the Future. 2nd edn. Indiana, Wiley.
- RIO TINTO. 2015. About Diavik. <http://www.riotinto.com/diamondsandminerals/diavik-2232.aspx>. [accessed 23 November 2015].
- ROEHRL, R., AND RIAHI, K. 2000. Technology dynamics and greenhouse gas emissions mitigation: A cost assessment. Technological Forecasting & Social Change, vol. 63, no. 2. pp. 231–261.
- ROY, B., AND McCORD, M.R. 1996. Multicriteria Mythology for Decision Aiding. London: Kluwer Academic Publishers.
- RYCROFT, M. 2014a. The potential of small hydro power plants in southern Africa. Gauteng: EE Publishers.
- RYCROFT, M. 2014b. Wheeling and dealing: Connecting electricity suppliers and customers. Gauteng: EE Publishers, 10 April pp. 45-48.
- SA CALCIUM CARBIDE. 2014. Environment. <http://www.andinagroup.com/sacc/environment.html> [accessed 7 April 2015].
- SABMILLER. 2014. Sustainable development. <http://www.sabmiller.com/index.asp?pageid=938> [accessed 7 April 2015].
- SAMANCOR. 2014. Sustainability. <http://www.samancorcr.com/content.asp?subId=20> [accessed 7 April 2015].
- SAPPI SOUTH AFRICA. 2014. Sustainability. <http://www.sappi.com/regions/sa/Sustainability/Pages/Group-sustainability.aspx> [accessed 7 April 2015].
- SAPVIA. 2013a. NERSA consultation on REFIT rates. Johannesburg: South African Photovoltaic Industry Association.
- SAPVIA. 2013b. South Africa PV industry – overview. Johannesburg: South African Photovoltaic Industry Association.

- SARS. 2015. Corporate income tax. <http://www.sars.gov.za/TaxTypes/CIT/Pages/default.aspx> [accessed 14 Jul 2015].
- SASOL. 2014. Sustainability. <http://www.sasol.com/sustainability/environment/climate-change> [accessed 7 April 2015].
- SAWEA. 2015. Wind industry growth. <http://www.sawea.org.za/resource-library/useful-information/109-industry-growth.html> [accessed 25 March 2015].
- SECCOMBE, A. 2015. Chamber of mines says carbon tax will damage industry. Business Day, 20 May. <http://www.bdlive.co.za/business/mining/2015/05/20/chamber-of-mines-says-carbon-tax-will-damage-industry> [accessed 25 November 2015].
- SCAW. 2014. Environment. <http://www.scaw.co.za/Pages/Environment.aspx> [accessed 7 April 2015].
- SCHULZE, R.E. 2007. Primary production, in R.E. Schulze (ed). South African atlas of climatology and agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 14.1.
- SNIM. 2013. Inauguration of SNIM's wind power plant. <http://www.snim.com/e/index.php/news-a-media/news/10-inauguration-of-snims-wind-power-plant.html> [accessed 1 February 2015].
- SOITEC. 2015. Concentrix™ technology in action around the world. <http://www.soitec.com/en/products-and-services/solar-cpv/our-references> [accessed 1 February 2015].
- SOLAIREDIRECT. 2012. The Dayton project. <http://www.solairedirect.com/international-presence/chile> [accessed 31 January 2015].
- SOLARPACK. 2012a. Calama solar 3 project. <http://www.solarpack.es/ing/calama.aspx> [accessed 30 January 2015].
- SOLARPACK. 2012b. Pozo Almonte solar project. <http://www.solarpack.es/ing/pozo-almonte.aspx> [accessed 31 January 2015].
- SOUTH AFRICAN RESERVE BANK. 2015. Inflation targets and results. <https://www.resbank.co.za/MonetaryPolicy/DecisionMaking/Pages/TargetsResult.aspx> [accessed 10 Jul 2015].

- SOUTHERN AFRICAN DEVELOPMENT COMMUNITY. 2012. Air quality.
<http://www.sadc.int/issues/environment-sustainable-development/air-quality>
 [accessed 7 April 2015].
- STATISTICS SOUTH AFRICA. 2015a. Gross Domestic Product: Second quarter 2015.
 Pretoria: Stats SA publications.
- STATISTICS SOUTH AFRICA. 2015b. Mining: Production and Sales, September 2015.
http://www.statssa.gov.za/?page_id=1856&PPN=P2041&SCH=6230. [accessed 22 November 2015].
- STEFANOPOULOS, K., YANG, H., GEMITZI, A., AND TSAGARAKIS, K.P. 2014.
 Application of the Multi-Attribute Value Theory for engaging stakeholders in
 groundwater protection in the Vosvozis catchment in Greece. *Science of the Total
 Environment*, vol. 470–471. pp. 26–33.
- STEIN, E.W. 2013. A comprehensive multi-criteria model to rank electric energy
 production technologies. (Report). *Renewable and Sustainable Energy Reviews*,
 vol. 22. pp. 640–54.
- STEINHAEUSER, I., SETHIA, A., JAISWAL, S., ROCHA OLIVEIRA, G., SEKINE, Y., AND
 ALVES, L.C. 2012. Global Corporate Renewable Energy Index (CREX).
 Copenhagen, Bloomberg New Energy Finance & Vestas.
- STELLAR ENERGY. 2013. Barrick-Western power plant. <http://www.stellarenergy.com/case-studies/commercial-solar/commercial/item/barrick-western-power-plant.html> [accessed 31 January 2015].
- STEWART, T.J., AND BELTON, V. 2002. Multi Criteria Decision Analysis: An Integrated
 Approach. Dordrecht: Kluwer Academic Publisher Group.
- STREIMIKIENE, D., BALEZENTIS, T., KRISCIUKAITIEN, A.I., AND BALEZENTIS, A.
 2012. Prioritizing sustainable electricity production technologies: MCDM approach.
 (Report). *Renewable and Sustainable Energy Reviews*, vol. 16, no. 5. pp. 3302–
 3311.
- SUBLIME. 2014. Company profile. http://www.sublime-technologies.com/index.php/about/company_profile [accessed 7 April 2015].

- SUN EDISON. 2013. Amanecer solar CAP. <http://www.sunedison.cl/chile> [accessed 31 January 2015].
- SWART. I. 2015. Draft Carbon Tax Bill released: South Africa moves to reduce greenhouse gas emissions. Johannesburg: Deloitte & Touche.
- THE CARBON REPORT. 2015. The proposed South African carbon tax. <http://www.thecarbonreport.co.za/the-proposed-south-african-carbon-tax/> [accessed 20 Jul 2015].
- TIDD, J. 2006. From Knowledge Management to Strategic Competence: Measuring Technological, Market and Organizational Innovation. 3rd edn. London, Imperial College Press.
- TOLEDANO, P. 2012. Leveraging the mining industry's energy demand to improve host countries' power structure. Working paper. New York: Colombia University.
- TOPCU, Y.I., AND ULENGIN, F. 2004. Energy for the future: An integrated decision aid for the case of Turkey, *Energy*, vol. 29, no. 1. pp. 137–154.
- TRANSNET. 2014. Environment public documents. <http://www.transnet.co.za/BusinessWithUs/EnvPubDocuments.aspx> [accessed 7 April 2015].
- TRIANANTAPHYLLOU, E. 2000. Multi-criteria Decision-making Methods: A Comparative Study. Dordrecht: Kluwer Academic Publisher Group.
- TROLDBORG, M., HESLOP, S., AND HOUGH, R.L. 2014. Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties. *Renewable and Sustainable Energy Reviews*, vol. 39. pp. 1173–1184.
- TSHIBALO, A.E., DHANSAY, T., NYABEZE, P., CHEVALLIER, L., MUSEKIWA, C., AND OLIVIER, J. 2015. Evaluation of the geothermal energy potential for South Africa. *Proceedings World Geothermal Congress 2015 (Melbourne)*. Johannesburg: University of South Africa.
- TSOUTSOS, T., DRANDAKI, M., FRANTZESKAKI, N., LOSIFIDIS, E., AND KIOSSES, I. 2009. Sustainable energy planning by using multi-criteria analysis application in the island of Crete. *Energy Policy*, vol. 37, no. 5. pp. 1587–1600.

- UNITED NATIONS. 2005. African regional implementation review for the 14th session of the Commission on Sustainable Development. New York: UNECA.
- VAN STADEN, P. 2015. Energy Management Sasol. Presentation. Johannesburg: Sasol.
- VAN RENSBURG, D. 2015. Carbon tax? What carbon tax? Fin24, 8 November.
<http://www.fin24.com/Economy/Carbon-tax-What-carbon-tax-20151106>. [25 November 2015].
- VAN ZYL, E. 2010. Bioenergy potential in sub-Saharan Africa. Stellenbosch: Stellenbosch University, Department of Microbiology.
- VERGNET WIND TURBINES. 2014. El Toqui. <http://www.vergnet.com/en/centrale-eltoqui.php> [accessed 30 January 2015].
- VESTAS. 2015. Technical specifications V100-2.0MW. Brochure. Denmark: Vestas Wind.
- VOA News. 2013. South Africa Mining Map. http://gdb.voanews.com/8EBA93BE-232B-47BB-9852-FCA2047409B0_w640_r1_s.png [accessed 22 January 2016].
- WAISSBEIN, O., GLEMAREC, Y., BAYRAKTAR, H., AND SCHMIDT, T.S. 2013. Derisking Renewable Energy Investment. New York: United Nations Development Program.
- WALWYN, D.R., AND BRENT, A.C. 2015. Renewable energy gathers steam in South Africa. *Renewable and Sustainable Energy Reviews*, vol. 41 pp. 390–401.
- WANG, J., JING, Y., ZHANG, C., SHI, G., AND ZHANG, X. 2008. A fuzzy multi-criteria decision-making model for trigeneration system. *Energy Policy*, vol. 36, no. 10. pp. 3823–3832.
- WASA. 2014. Wind atlas for South Africa. <http://www.wasaproject.info> [accessed 2 April 2015].
- WATSON, G.H. 2007. Strategic Benchmarking Reloaded with Six Sigma: Improve Your Company's Performance Using Global Best Practice. New Jersey, John Wiley & Sons.
- WERNECKE, G. 2015. Senior Project Manager, Cronimet Mining Power Solutions SA. Johannesburg: Personal interview, [May, 6].

- WESTERMANN, G., AND SEHL, I. 2006. Developing a balanced scorecard based benchmarking approach for tourist destinations. Proceedings of the European Innovation Pressure Conference, Tampere, Finland, 15-17, March.
- WILLIAMS, N.C. 2014. Demand reduction and responsive strategies for underground mining. PhD thesis. Exeter, England: University of Exeter.
- WIRTH, G. 2015. Technical manager at Cronimet Power Solutions. Unterhaching: Cronimet Power Solutions.
- WORLD BANK GROUP. 2015a. Africa Power-Mining projects database. Washington D.C.: World Bank Group.
- WORLD BANK GROUP. 2015b. Commodity markets outlook. Washington D.C.: World Bank Group.
- WORLD BANK GROUP. 2015c. Economic data South Africa.
<http://data.worldbank.org/country/south-africa>. [accessed 22 November 2015].
- WOUTER, F. 2014. Energy management AGA. Presentation. Johannesburg: AngloGold Ashanti.
- YELLAND, C. 2013. Analysis of the structure of Eskom's special electricity pricing deals with BHP Billiton. EE publishers. <http://www.ee.co.za/article/analysis-of-the-structure-of-eskoms-special-electricity-pricing-deals-with-bhp-billiton.html> [accessed 4 April 2015].
- ZIKMUND, W.G., AND BABIN, B.J. 2010. Exploring marketing research. 10th edition. Mason: Thomson.

Addendum A: Interview Protocol

Date	Type of contact	Location of Meetings	Job description	Expert area
2013 March – 2014 June	Meeting	Cape Town	ProcewaterhouseCoopers – Director / Renewable Energy	Energy - Mining
2013 April – 2013 July	Telephone conference		Deloitte – Director / Power Industry Leader	Energy - Mining
2013 September – 2014 June	Meeting	Cape Town	Ernst & Young – Director / Climate Change and Sustainability Service	Energy
2014 January – 2014 March	Email		Energy Intensive User Group - Chairperson	Energy - Mining
2014 March – 2014 July	Meeting	Cape Town	Gestamp Solar – Project Development Manager	Energy
2014 March – 2014 July	Meeting	Somerset West	Power Solutions – Managing Director	Energy
2014 March – 2014 July	Meeting	Cape Town	AE AMD Renewable Energy – Site Development	Energy
2014 April	Meeting	Cape Town	Aurora Energy Solutions - Director	Energy
2014 May – 2015 February	Meeting	Cape Town	University of Cape Town – Statistical Science and Decision Analysis	MCDA
2014 May – 2015 June	Meeting	Stellenbosch	Cennergi – Head of Advocacy	Energy - Mining
2014 June – 2015 May	Meeting	Munich (Germany)	Cronimet Power Solution – Managing Director	Energy - Mining
2014 June – 2015 May	Meeting	Munich (Germany)	Cronimet Power Solution – Technical Manager	Energy - Mining
2014 June – 2015 May	Meeting	Cape Town	G7 Renewable Energies – Managing Director	Energy
2014 June – 2015 May	Meeting	Johannesburg	AngloGoldAshanti – Energy Engineer	Mining
2014 July	Meeting	Stellenbosch	Norton Rose Fulbright – Environmental Layer	Energy
2014 August	Meeting	Cape Town	University of Cape Town - Statistical Science and Decision Analysis	MCDA
2014 August – 2015 May	Meeting	Stellenbosch	CREO Design - CEO	Mining
2014 August – 2015 May	Meeting	Johannesburg	Sasol – Category manager: Utilities Supply Chain	Energy - Mining
2014 September	Meeting	Johannesburg	Cronimet Chrome Mining SA – Commercial manager	Mining
2014 September	Meeting	Johannesburg	Cronimet Chrome Mining SA – Technical Assistant	Energy - Mining
2014 September – 2015 March	Meeting	Stuttgart (Germany)	Bosch – Sales Manager / Industrial Batteries	Energy
2014 November – 2015 May	Meeting	Johannesburg	Cronimet Power Solution – Senior project manager	Energy - Mining
2015 February – 2015 April	Teleconference		HRP Geopower	Energy
2015 February – 2015 May	Meeting	Johannesburg	MSR Tormin Mine – Engineer	Energy - Mining
2015 April	Meeting	Cape Town	Eskom – Chief Engineer	Energy

Addendum B: Questionnaire for mines to identify evaluation criteria



UNIVERSITEIT • STELLENBOSCH • UNIVERSITY
jou kennisvennoot • your knowledge partner

7 November 2014

Interview

To Reveal the Criteria Mining Corporations utilize to Evaluate possible On-Site Electricity Generation

Sources

PhD Student: Roman Votteler

Supervisor:

Prof Alan Brent

Contact details:

Roman Votteler

Cell: +27 73 4431973

E-mail: votteler.roman@gmail.com

School of Public Leadership

•

Sustainable Development

www.spl.sun.ac.za



Centre for Renewable and Sustainable Energy Studies

www.crses.sun.ac.za



Sustainability Institute

www.sustainabilityinstitute.net



RENEWABLE & SUSTAINABLE
ENERGY STUDIES



SUSTAINABILITY
INSTITUTE

Study Overview

Part 1 – (past) analyzed the macroeconomic influences at the moment and in the future on the market of renewables with mining locations in South Africa

Part 2 - (now) reveals the criteria mining corporations use to evaluate possible on-site electricity sources.

Part 3 – (later) creates a model, which uses the criteria to analyze and compare different sources. The model will be implemented with real-time data of companies realizing on-site electricity projects.

Benefits for mining company

- A more structured and optimized understanding to select the best possible on-site electricity source, especially towards new technologies like renewables
- Evaluation of strength and weaknesses of different on-site electricity generation sources, based on own criteria
- A comparison analysis of present sources (diesel generators) to renewable sources (solar pv; wind; battery storage; +hybrid with diesel generators)

Interview guide

Obtaining feedback from professionals of the business is vital to the research process. Your responses are voluntary and are confidential. Responses will not be identified by individuals. All responses will be compiled together and analysed as a group. It should take about 45 minutes of your time. I would appreciate it, if you are taking the time to complete the following survey with me.

1. Introduction

Mine Specific

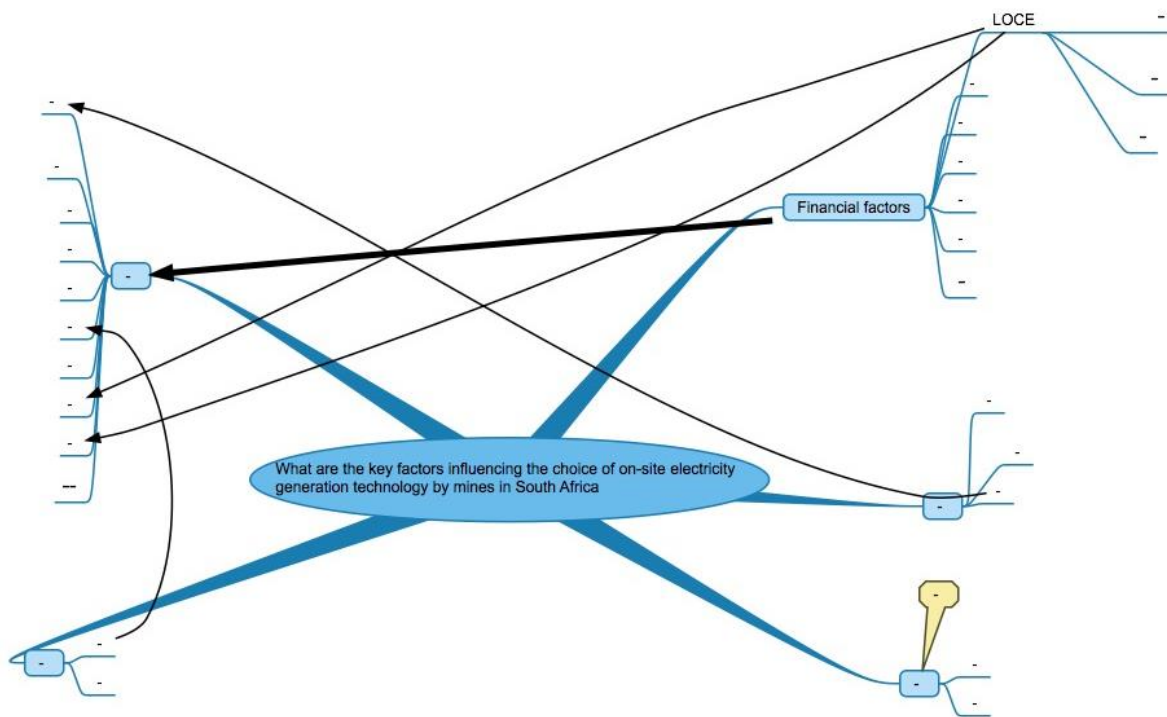
- 1.1. What is your position in the company?
- 1.2. What type of resources are you mining?
 - 1.2.1. Where would you see most potential for renewables and why?
- 1.3. Have you got mines that are not grid connected or use on-site generations on a consistent base?
- 1.4. What is your yearly range of average electricity consumption at mining locations?
 - 1.4.1. Baseload consumption?
 - 1.4.2. Load factors?
- 1.5. How much per cent are electricity cost from your total production cost?
- 1.6. Have you considered using renewables
 - 1.6.1. If yes, why did you realize it or why not?
 - 1.6.2. When was it?
- 1.7. Is the mining location(s) grid connected
 - 1.7.1. If yes, how much is the price per Kw/h to Eskom at the moment?
 - 1.7.2. How much per cent of your total electricity consumption does Eskom supply?
 - 1.7.3. How much do you produce on your own?
- 1.8. What are your present on-site electricity sources?
 - 1.8.1. What is the Levelized Cost of Electricity (LCOE)¹⁰ price per R/kWh on how many years?
 - 1.8.2. What is the initial investment cost per kW?
 - 1.8.3. What is the operating electricity cost (R/kWh)?

¹⁰ This method considers the predicted lifetime-generated energy and estimates a price per unit of electricity produced (R/kWh). It includes the initial capital, discount rate, as well as the costs of continuous operation, fuel, and maintenance.

2. Main part

Manual

The main part of the interview will be in form of a post-it / mind-map session. The respondent is encouraged to mention every criterion he / she can think of. The criterion should be as precise as possible. In addition, the respondent will be encouraged to create sub-criteria to assure a detailed illustration. The following Figure serves as a visual example.



Type of electricity source to be evaluated

The purpose of this section of the interview is to reveal the criteria according to which XXXXXX is evaluating possible electricity sources for a mining location. The point of view should be from the planning process of a new mining location, where different sources are investigated to find the most effective one.

To be able to use the same criteria for the evaluation, the on-site electricity-generating source should have the following characteristics (scenario):

- Be its own entity and able to produce electricity by itself (including fuel)
- Own investment without third parties (focus on technology; not business model)
- Possible example sources: diesel generator, Solar Pv; Wind turbine; Eskom

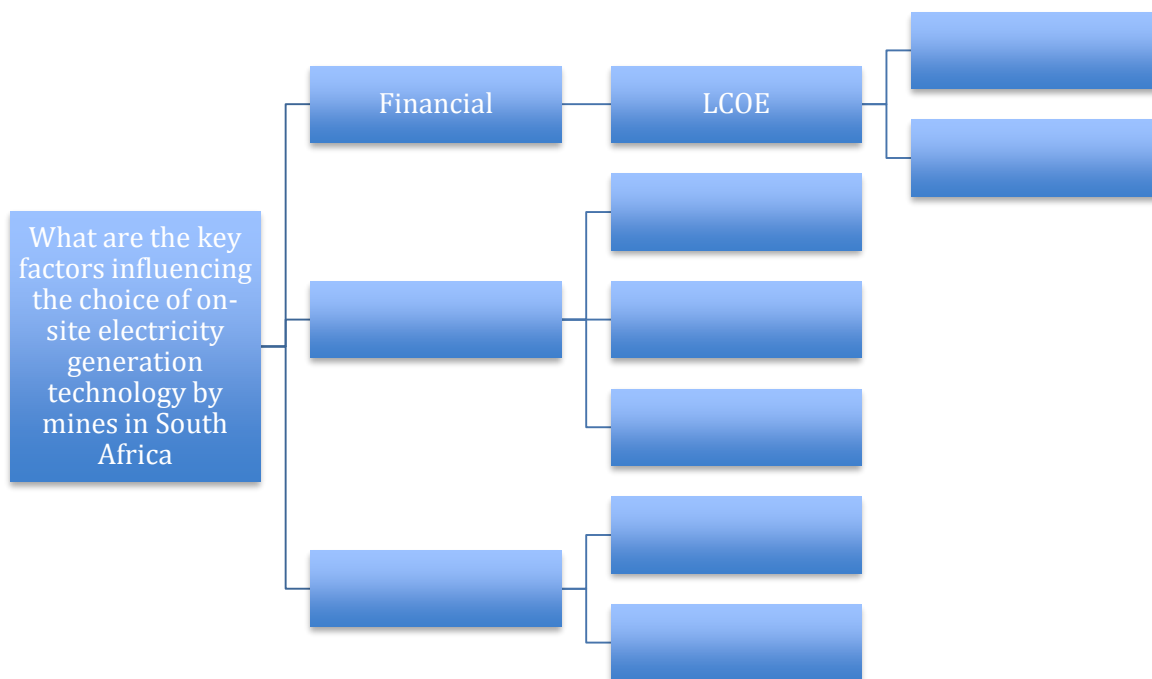
Points to keep in mind

1. Identify main criteria categories (Financial; Operational...)
2. Evaluation criteria
 - Can the criteria be explained in more detail to reveal possible sub-criteria.
 - Detailed description of the criterion's purpose
 - How is the criterion measured
3. Possible links between criteria

3. Conclusion

The mind map that was created during this interview will be used to create a decision tree as presented in an example figure underneath. Reason for the transformation is that certain statistical requirements in the inter criteria relationships have to be met.

Would it be acceptable for you to confirm the created decision tree, to confirm that it reflects your evaluation criteria. It will be sent to you via e-mail within the next two weeks.



- Which information from this field of research would you be interested in?

- Would you say research is of value to generate more clarity, as the topic of renewables is still relatively new
- Have you got any further suggestions for my study? Is there anything you would alternate?

Addendum C: Semi-structured questionnaire for electricity sources data



UNIVERSITEIT • STELLENBOSCH • UNIVERSITY
jou kennisvenoot • your knowledge partner

22 June 16

Interview

To reveal the data of different on-site energy resources options for mining operations in South Africa

PhD Student: Roman Votteler

Supervisor:

Prof Alan Brent

Contact details:

Roman Votteler

Cell: +27 73 4431973

E-mail: votteler.roman@gmail.com



School of Public Leadership

•

Sustainable Development

www.spl.sun.ac.za



Centre for Renewable and Sustainable Energy Studies

www.crses.sun.ac.za



Sustainability Institute

www.sustainabilityinstitute.net



RENEWABLE & SUSTAINABLE
ENERGY STUDIES



SUSTAINABILITY
INSTITUTE

Study Overview

Part 1 – (past) analyzed the macroeconomic influences at the moment and in the future on the market of renewables with mining locations in South Africa

Part 2 - (past) reveals the criteria mining corporations use to evaluate possible on-site electricity sources.

Part 3 – (now) creates a model, which uses the criteria to analyze and compare different sources. The model will be implemented with real-time data of a company realizing on-site electricity projects.

Planned outcome

- A more structured and optimized understanding to select the best possible on-site electricity source, especially towards new technologies like renewables
- Evaluation of strength and weaknesses of different on-site electricity generation sources, based on the criteria of mining corporations
- A comparison analysis of present sources (diesel generators; gas turbines) to hybrid-renewable sources (solar pv; wind)

Interview guide

Obtaining feedback from professionals of the business is vital to the research process. Your responses are voluntary and are confidential. If you wish, your responses will stay anonymous and will not be identified under the companies name XXX. It should take about 45 minutes of your time. I would appreciate it, if you are taking the time to complete the following survey with me.

4. Introduction

4.1. In which energy-generating sources are you specialized in?

4.2. On what size of projects do you focus on?

4.3. Do you see the market for renewables with mining corporations increasing or decreasing?

4.3.1. Why?

4.4. Where would you see the need for more improvement to increase the market of on-site renewables at mining locations? Education, technological improvement etc?

4.5. Assuming that a hybrid source with a constant 10MW base load capacity is producing on full capacity for 24h, what are the supplying ratios and the capacity size of each source?

4.5.1. Hybrid Solar PV / Diesel generator

____% / ____% ; ____MW / ____MW

4.5.2. Hybrid Wind turbines / Diesel generator

____% / ____% ; ____MW / ____MW

4.5.3. Hybrid Geothermal / Diesel generator

____% / ____% ; ____MW / ____MW

4.5.4. Hybrid Solar PV / Eskom

____% / ____% ; ____MW / ____MW

4.5.5. Hybrid Wind turbines / Eskom

____% / ____% ; ____MW / ____MW

4.5.6. Hybrid Geothermal / Eskom

____% / ____% ; ____MW / ____MW

5. Main part

The main part of the interview will be directed to gather the data for each selected on-site energy-generating source to the criteria in Table 1. The criteria are revealed from and used by mining corporations to evaluate possible on-site energy generating sources.

Table 1: Evaluation criteria

Economy						
Investment cost	Operating and maintenance costs	Prediction of fuel costs	Prediction of initial investment costs	Levelised electricity cost	Net present value	
Technology						
Efficiency	Safety	Implementation period	Reliability	Maturity	Service level	
Environment						
CO ₂ emission	Noise	Land requirement				
Social						
Job creation	Corporate image	Effect on community				

As some data would vary from location to location, the average values (experience) for projects in South Africa should be provided. For wind generation an annual power density of 600 W/m² is assumed. For solar PV an annual sum of horizontal irradiation of at least 2000 kWh/m² is assumed. The capacity of each project should amount to 10MW, to assure comparability. The following energy sources are of interest:

- Diesel generator
- Hybrid diesel generator / Solar PV
- Hybrid diesel generator / Wind turbines
- Hybrid diesel generator / Geothermal “Hot dry rock”
- Gas turbines
- Hybrid Eskom / Solar PV
- Hybrid Eskom / Wind turbines
- Hybrid Eskom / Geothermal “Hot dry rock”

The combined values are calculated according to the percentage contribution of electricity supply or project size ratios to provide a 10MW capacity operating 24h.

5.1. Economy

5.1.1. What is the initial investment cost?

Investment Cost		Includes all costs regarding the planning, purchase and installation of the electricity source		
Initial investment cost = Currency / kW			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____ kW	_____ kW	_____ kW	_____ kW	_____ kW

5.1.2. What are the operating & maintenance costs?

Operating & Maintenance Costs		Costs entail employee's salaries, and the products and services for the system operation. Maintenance costs assure that the system is in operating condition, to prolong the system life and avoid failures that cause downtime.		
O&M costs = Currency / kW per year			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____ kW	_____ kW	_____ kW	_____ kW	_____ kW

5.1.3. What are the fuel costs?

Fuel costs		The cost of fuel to power the electricity source		
Fuel costs = Currency / kWh			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____ kWh	_____ kWh	_____ kWh	_____ kWh	_____ kWh

5.1.4. Where do you expect the fuel costs to be in 5 years?

Prediction of Fuel Costs		Provides a prediction of the fuel price consumed by the electricity source to produce electricity		
Fuel costs = Currency / kWh or %			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____ kWh	_____ kWh	_____ kWh	_____ kWh	_____ kWh

5.1.5. Where do you expect the initial investment costs to be in 5 years?

Prediction of initial investment costs		This criterion provides an estimation of how the initial investment cost will develop. If the technology is relatively new, possible price drops can be expected.		
Initial investment cost = Currency / kW or %			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____ kW	_____ kW	_____ kW	_____ kW	_____ kW

5.1.6. What are the current levelized electricity costs?

Levelized Electricity Cost		Measures the Rand cost per kWh including all costs occurring from the initial investment till the end of the predicted life-time, which is put into relation to the projected output of kWh in the same time-span.		
LEC = Currency / kWh		No repetition is needed if values are identical		
$LCOE = \frac{PCI - \sum_{n=1}^N \frac{DEP + INT}{(1 + DR)^n} TR + \sum_{n=1}^N \frac{LP}{(1 + DR)^n} + \sum_{n=1}^N \frac{AO}{(1 + DR)^n} (1 - TR) - \frac{RV}{(1 + DR)^N}}{\sum_{n=1}^N \frac{\text{Initial kWh} \times (1 - SDR)^n}{(1 + DR)^n}}$		PCI = Own Initial investment DEP = Depreciation INT = Interest paid DR = Discount Rate LP = Loan Payment AO = Annual operations costs (Fuel; O&M) TR = Tax Rate RV = Residual Value SDR = System Degradation Rate AOE = Annual Operating cost escalation N = Number of Years		
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____ kWh	_____ kWh	_____ kWh	_____ kWh	_____ kWh
PCI = _____ DEP = _____ INT = _____ DR = _____ LP = _____ AO = _____ TR = _____ RV = _____ SDR = _____ AOE = _____ N = _____	PCI = _____ DEP = _____ INT = _____ DR = _____ LP = _____ AO = _____ TR = _____ RV = _____ SDR = _____ AOE = _____ N = _____	PCI = _____ DEP = _____ INT = _____ DR = _____ LP = _____ AO = _____ TR = _____ RV = _____ SDR = _____ AOE = _____ N = _____	PCI = _____ DEP = _____ INT = _____ DR = _____ LP = _____ AO = _____ TR = _____ RV = _____ SDR = _____ AOE = _____ N = _____	PCI = _____ DEP = _____ INT = _____ DR = _____ LP = _____ AO = _____ TR = _____ RV = _____ SDR = _____ AOE = _____ N = _____

5.1.7. What is the Net Present Values?

Net Present Value		A financial method to define the total present value of a series of annually cash inflows/outflows during the life-span. The cash flows are discounted back to its present and added up. The final present amount is compared to the initial investment costs.		
NPV = Currency amount		No repetition needed as same values than previous questions		
$NPV = -C_0 + \sum_{i=1}^T \frac{C_i}{(1+r)^i}$		<ul style="list-style-type: none"> • $-C_0$ = Own Initial investment • C = Cash flow (o&m + fuel + loan payment - residual value + interest paid – tax savings) • r = Discount rate • T = Time 		
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____ kWh	_____ kWh	_____ kWh	_____ kWh	_____ kWh

5.2. Technology

5.2.1. How would you rate the safety for people working with the facility?

Safety	Safety relates to the degree of safety for employees working on site			
<div>(1) Frequently occurring incidents to hospitalize workers</div> <div>(2) In between 1 and 3</div> <div>(3) Severe injuries to hospitalize worker can occur sparingly</div> <div>(4) In between 4 an 5</div> <div>(5) Occurring incidents force worker to rest at home</div> <div>(6) In between 5 and 7</div> <div>(7) The hard work causes frequent light injuries, but work can be continued</div> <div>(8) In between 7 and 9</div> <div>(9) Sparingly occurring incidents with light injuries</div> <div>(10) In between 9 and 11</div> <div>(11) No incidents of any form are expected during lifetime of the system</div>				
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____	_____	_____	_____	_____

5.2.2. How long would you estimate the average implementation period?

Implementation Period	States the amount of time needed to realize the project from planning to first date of operation			
Implementation period = months or years			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____ months	_____ months	_____ months	_____ months	_____ months

5.2.3. What is the capacity factor?

Reliability		Is defined as the capacity of a system to performed as designed and planned. Stated as the capacity factor (i.e. the ratio of the actual power output to the theoretical maximum power output from the technology over a period of time)				
capacity factor = %						
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom		
_____ %	_____ %	_____ %	_____ %	_____ %		

5.2.4. How would you evaluate the maturity of the different technologies?

Maturity	Refers to the development stage of the technology. The stages range from “only tested in laboratories” to “close to reaching the theoretical limits of efficiency”				
(1) only performed in pilot plants, where the demonstrative goal is linked to the experimental one, referring to the operating and technical conditions					
(2) between 1 and 3					
(3) available on the market, but the improvement rate in coming years is expected to be very high					
(4) between 3 and 5					
(5) well established in the market but further efficiency improvements are expected					
(6) between 5 and 7					
(7) technologies that could be still improved but are close to maximum efficiency					
(8) between 7 and 9					
(9) close to reaching the theoretical limits of efficiency.					
(10) between 9 and 10					
(11) technological plateau is reached					
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom	
_____	_____	_____	_____	_____	

5.2.5. How would you evaluate the service level for the different sources available in South Africa?

Service Level	Measures the availability of experts and spare parts to repair damaged equipment in South Africa.			
(1) More than 4 weeks (2) 4 weeks (3) 3 weeks (4) 2 weeks (5) 1 week (6) 4 days (7) 3 days (8) 2 days (9) 1 day (10) less than 1 day				
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____	_____	_____	_____	_____

5.3. Environment

5.3.1. What is the amount of CO₂ emitted by the on-site electricity source?

CO ₂ Emission	Measures the emission of a colourless, odourless and tasteless gas, which is mainly emitted through the combustion of coal, oil and gas.			
kgCO ₂ /kWh			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____	_____	_____	_____	_____

5.3.2. What is the noise volume produced by the 1MW on-site source?

Noise	Is the machine-created sound that disrupts human and animal daily life			
If the combined value is not known, the louder on-site source is counted				
Decibel = dB/kW			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____	_____	_____	_____	_____

5.3.3. What is the land requirement for a 1MW project size?

Land requirement	The amount of land the electricity source requires for a certain capacity			
The combined value is used.				
Square meter = m ²			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____	_____	_____	_____	_____

5.4. Social

5.4.1. How many jobs are created by for 1MW?

Job creation	The amount of people employed during the life-time cycle of a energy system			
Number of jobs created			No repetition is needed if values are identical	
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____	_____	_____	_____	_____

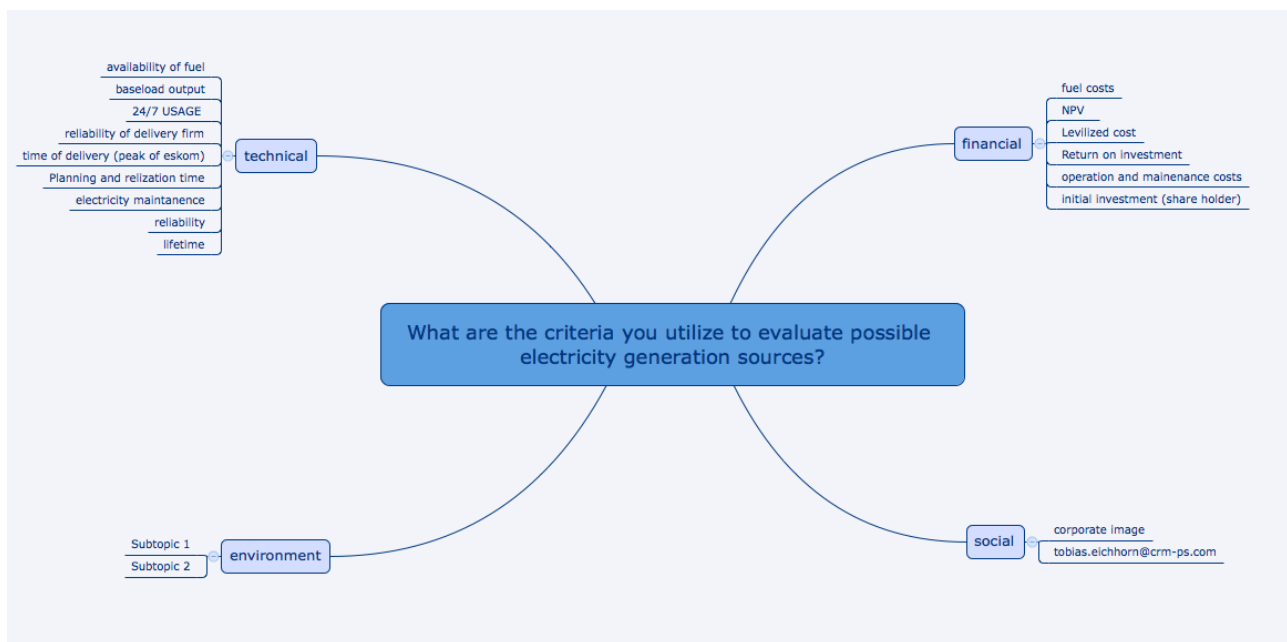
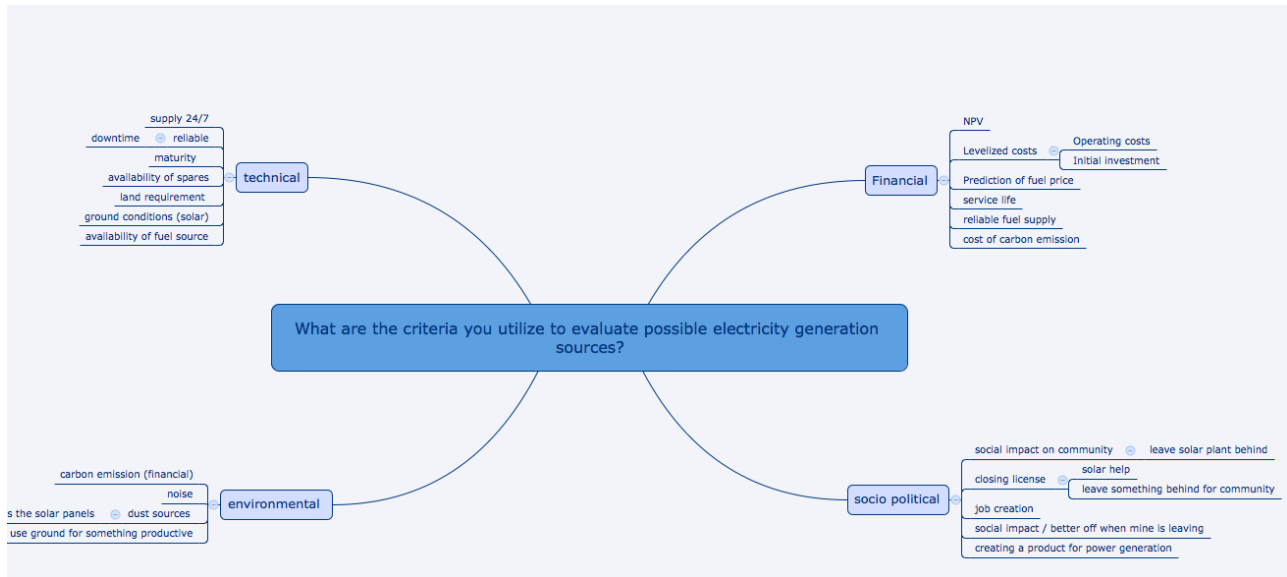
5.4.2. How would you evaluate the impact of the electricity source on the corporate image?

Corporate Image	The possible impact of the electricity source on the corporate identity in the minds of diverse publics, such as customers, investors and employees			
(1) Negative influence through public media (2) In between 1 and 3 (3) Negative influence within the industry (4) In between 3 and 5 (5) Negative influence on business partners (6) In between 5 and 7 (7) Negative influence within the own company (8) In between 7 and 9 (9) No impact (10) In between 9 and 11 (11) Positive influence within the own company (12) In between 11 and 13 (13) Positive influence on business partners (14) In between 13 and 15 (15) Positive influence within the industry (16) In between 15 and 17 (17) Positive influence through public media				
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____	_____	_____	_____	_____

5.4.3. How would you evaluate the impact on the surrounding community?

Effect on community	A possible impact on the surrounded residents, after the mine has to be closed. The community could further utilize the electricity source.			
	Please specify, in case several options per source are suitable			
(1) The pollution is negatively affecting the health standards (2) In between 1 and 3 (3) No affect on health, but factors like noise lowering quality of life (4) In between 3 and 5 (5) No impact (6) In between 5 and 7 (7) Uplift community, by leaving a source of electricity after mine closure (8) In between 7 and 9 (9) Uplift community by leaving electricity source and increase quality of life				
Diesel Generator	Solar PV	Wind turbines	Geothermal	Eskom
_____	_____	_____	_____	_____

Addendum D: Post-it-sessions



Addendum E: Mining interviews to identify value function and importance weight

Roman Votteler

Interview

A Multi Criteria Decision Analysis model adapted to mining corporations to select electricity generating sources



12 August 2015

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

1

Agenda

Roman Votteler

1. The research project

- Research structure

2. The Interviews

- To reveal the data of different on-site energy resources
- To reveal the preference and importance of the evaluation criteria

3. The Outcome

12 August 2015

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

2

01

The Research Project

12 August 2015

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

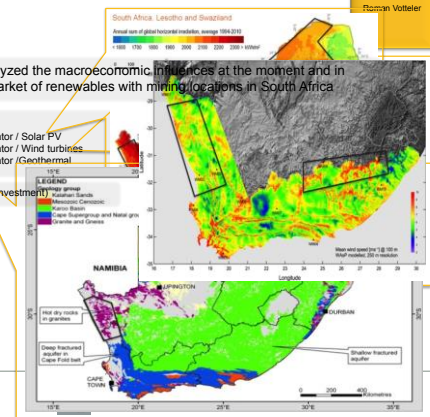
1

Technology data

Part 1 – (past) analyzed the macroeconomic influences at the moment and in the future on the market of renewables with mining locations in South Africa

- Diesel generator
- Hybrid diesel generator / Solar PV
- Hybrid diesel generator / Wind turbines
- Hybrid diesel generator / Geothermal

Self-Generation (Own Investment)



12 August 2015

Research Structure

Part 1 – (past) analyzed the macroeconomic influences at the moment and in the future on the market of renewables with mining locations in South Africa

Part 2 – (past) reveals the criteria mining corporations use to evaluate possible on-site electricity sources.

Part 3 – (now) creates a MCDA model with the criteria to analyze and compare different sources.

10MW capacity

Economy	Investment Cost
	Operating & Maintenance Costs
	Fuel costs
	Prediction of Fuel Costs
	Annual cost of electricity
	Annual cost of electricity
	Net Present Value
Technology	Safety
	Life span
	Capacity factor
	Maturity
	Service Level
Environment	CO2 Emission
	Noise
	Land requirement
Social	Job creation
	Corporate Image
	Effect on community

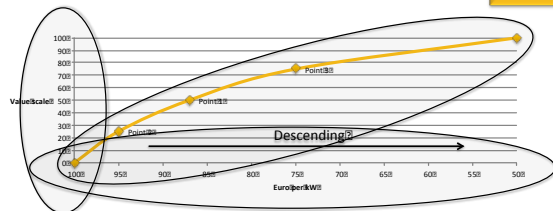
12 August 2015

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

5

Interview 1 (11.02.2015)

Initial Investment Cost




- Solar Hybrid 100kW
- Diesel Generator 100kW
- Wind Hybrid 8kW

12 August 2015

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

7




Interview 2 (18.02.2015)

Initial Investment Cost

Roman Völtter

Section	Initial Investment Cost
1	0
2	250
5	500
6	750
10	950

12 August 2015



UNIVERSITÄT
STELLENBOSCH
UNIVERSITY

8

The graph illustrates the decreasing trend of electricity generation costs in Germany over a 20-year period. The Y-axis, labeled 'Value/cost/kWh', ranges from 0 to 1000. The X-axis, labeled 'Year', ranges from 1990 to 2010. A horizontal red line at the 1000 mark represents the 'Initial investment cost'. A yellow curve starts at approximately 400 in 1990 and rises to meet the 1000 mark in 2010. Three boxes at the bottom indicate the cost levels for different technologies: 'Solar Diesel Hybrid' (approx. 400 in 1990), 'Wind Diesel Hybrid' (approx. 400 in 2000), and 'Diesel generator' (approx. 1000 in 2010).

Figure 1 displays the relative importance of various variables for three different models: Citizens (0.333), General population (0.333), and Transport entrepreneurs (0.333). The variables are ranked by their relative importance, with the highest importance variable for each model being 'Transport frequency'.

Model	Variable	Relative Importance
Citizens (0.333)	Transport frequency	0.85
	Land use	0.25
	Traffic	0.20
	Traffic density	0.15
	Traffic volume	0.10
	Economic efficiency	0.05
	Property value	0.02
General population (0.333)	Transport frequency	0.85
	Land use	0.25
	Traffic	0.20
	Traffic density	0.15
	Traffic volume	0.10
	Economic efficiency	0.05
	Property value	0.02
Transport entrepreneurs (0.333)	Transport frequency	0.85
	Land use	0.25
	Traffic	0.20
	Traffic density	0.15
	Traffic volume	0.10
	Economic efficiency	0.05
	Property value	0.02

[illegible]

The Outcome

2. Outcome – Comparison of Alternatives according to Scoring Matrix

The figure consists of two radar charts comparing the 'Coal' and 'Maximum renewable' alternatives across 11 criteria. The criteria are: Cost, National Industry, Energy Dependency, Employment, Visual Impact, Noise, Local Income, Diversity of Mix, Rate of Dispatchable Power, Investment in Transmission Grid, and CO2 emissions. The 'Coal' chart shows high scores in Cost, National Industry, Energy Dependency, Employment, Visual Impact, Noise, Local Income, Diversity of Mix, Rate of Dispatchable Power, Investment in Transmission Grid, and CO2 emissions, but low scores in Public Health and Land Use. The 'Maximum renewable' chart shows high scores in Public Health, Land Use, CO2 emissions, Investment in Transmission Grid, Rate of Dispatchable Power, Diversity of Mix, Noise, Local Income, Visual Impact, Employment, and Energy Dependency, but high scores in Cost and National Industry.

12 August 2015

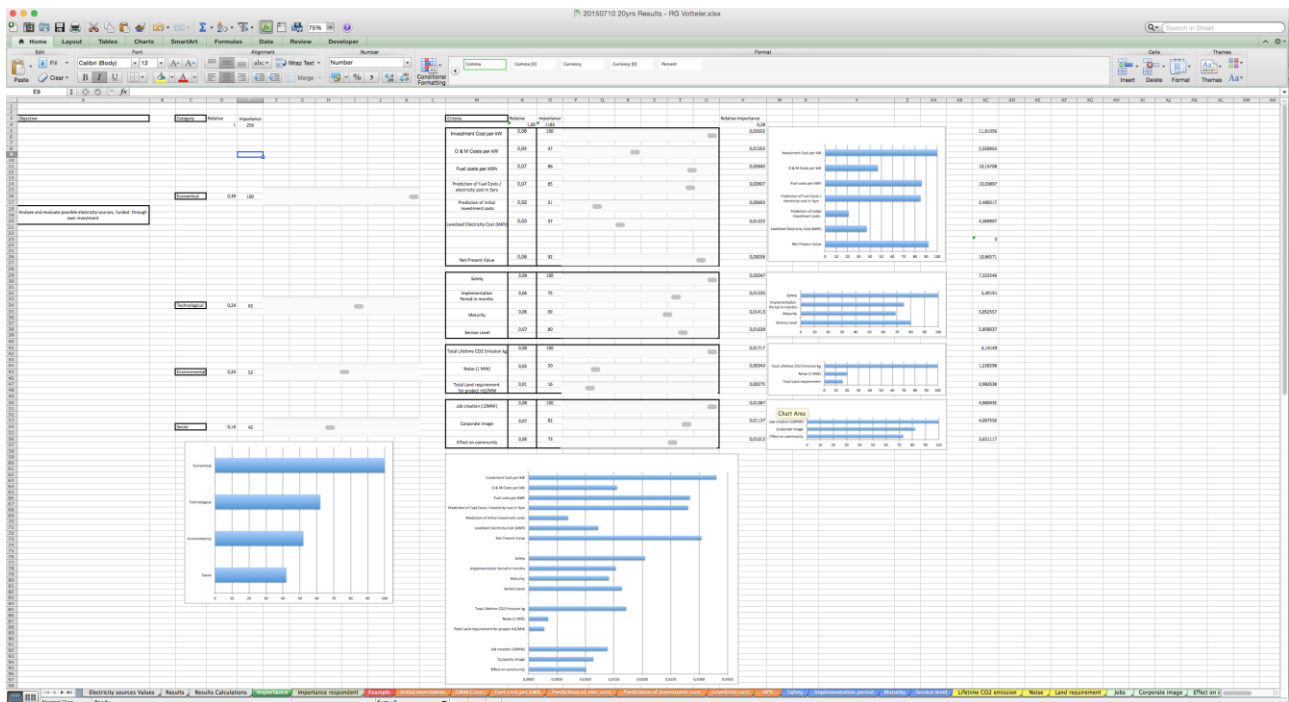
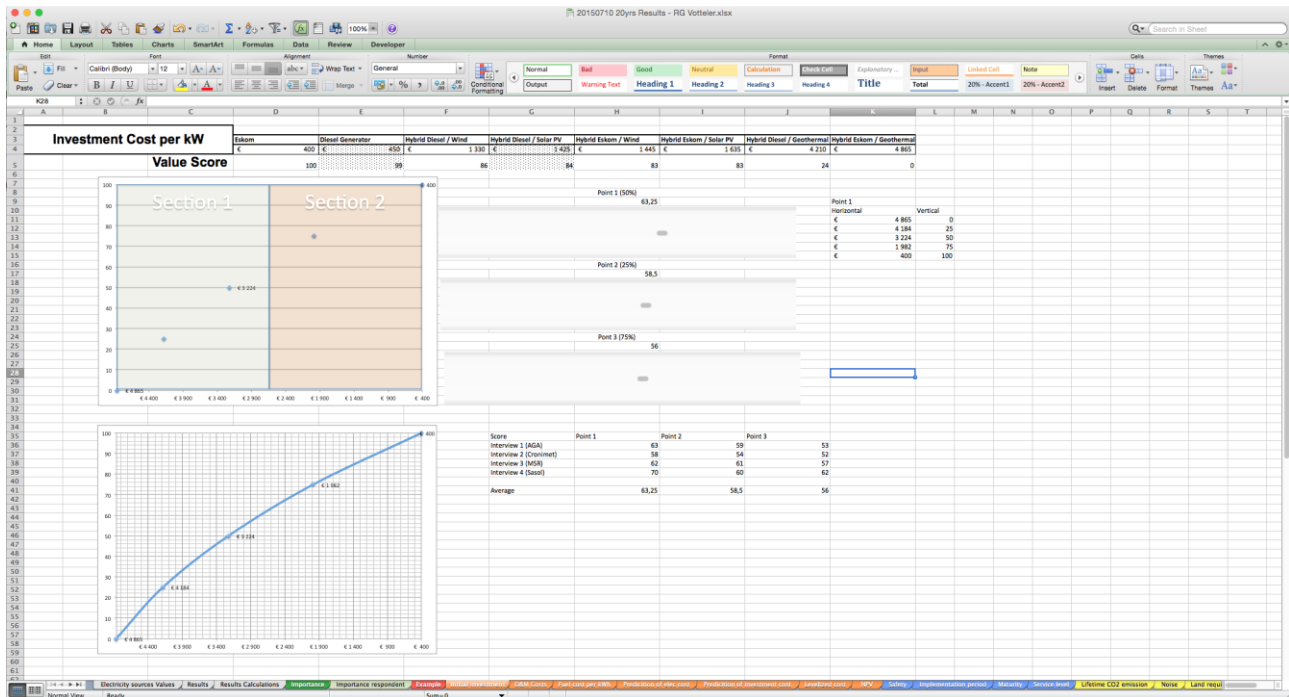
UNIVERSITÄT
STELLENBOSCH
UNIVERSITY

12

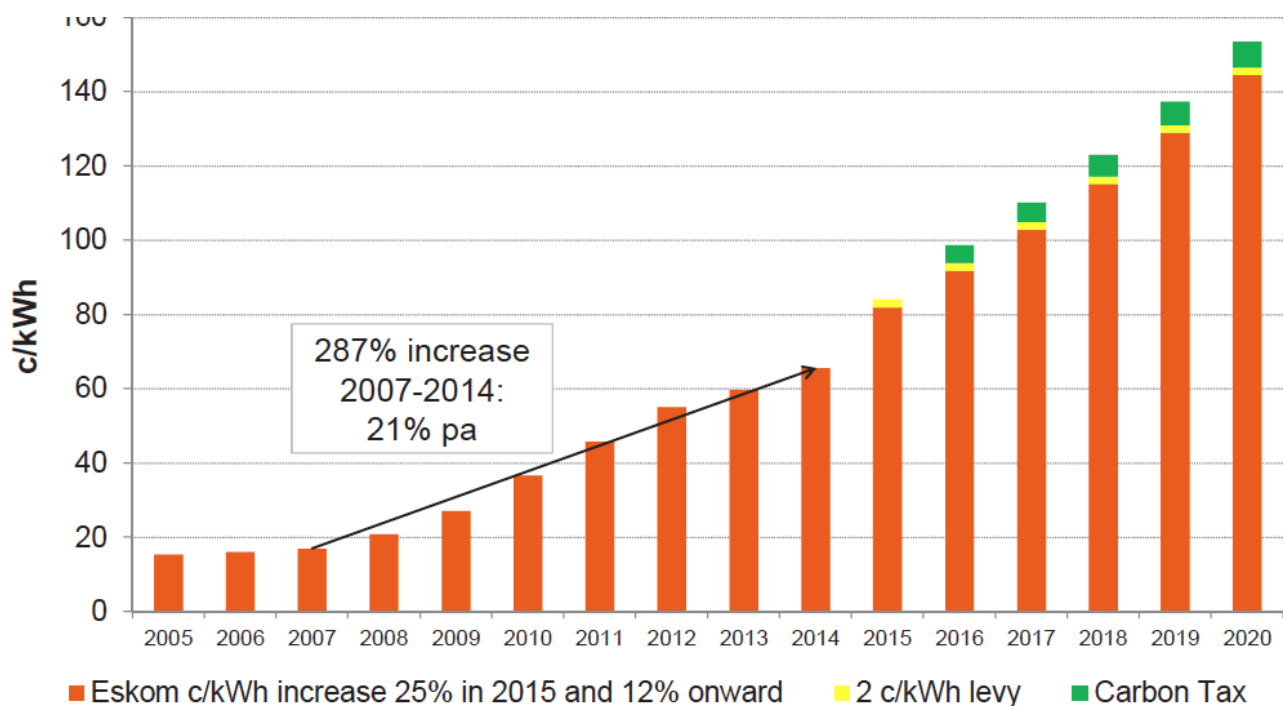
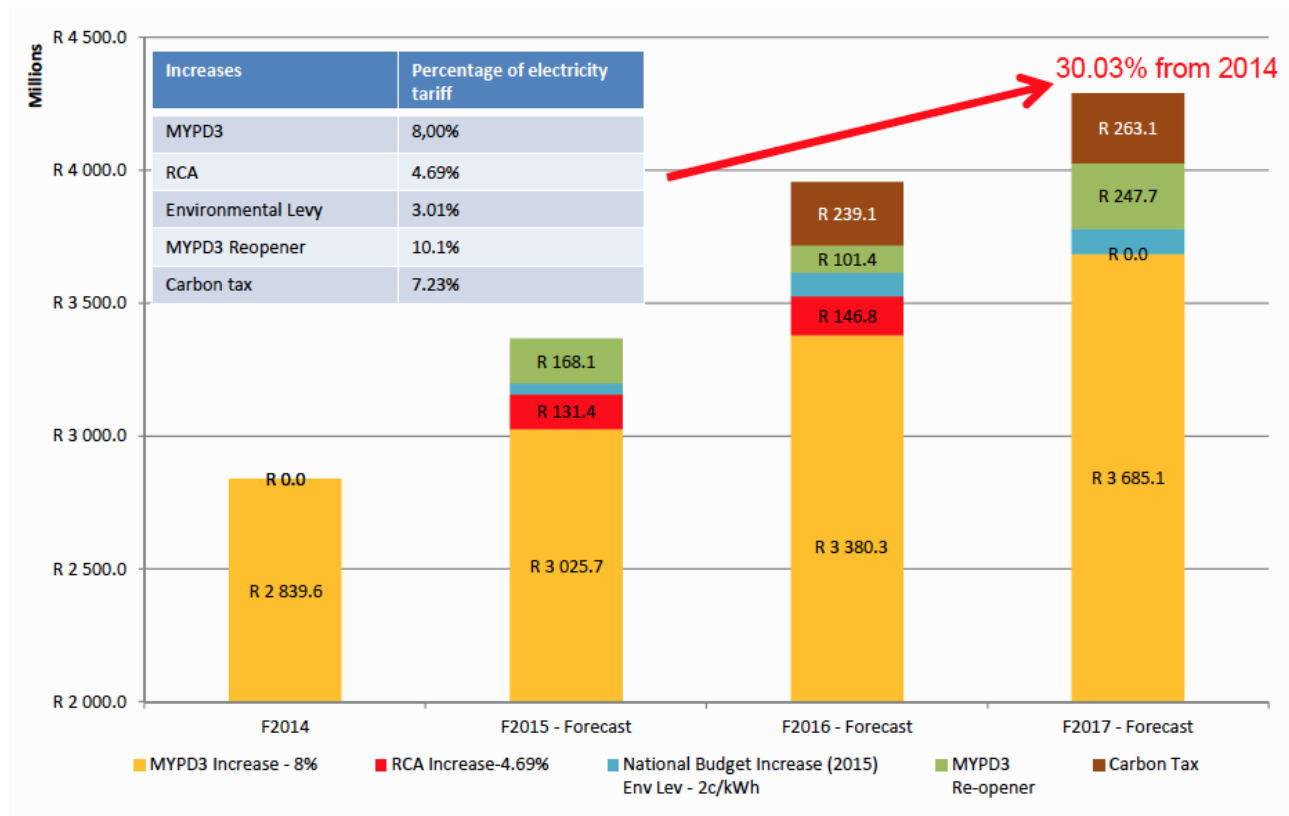
Type	Value	Type	Value
Project Size (kW)	10000	Annual change of fuel costs in %	7%
Depreciation Rate	15%	O & M cost escalation in %	2%
Tax Rate	28%	Annual system degradation	1%
Discount Rate	10%	Project ratio Diesel	Solar 0,75 Wind 0,85
Debt Percentage	50%	Project ratio Eskom	Solar 0,95 Wind 0,95
Equity Percentage	50%		Geothermal 0,95
Years of loan payment	10		
Cost of Debt	13,4%		
Number of years	20		Geothermal 0,95

The image shows a presentation slide with a yellow header and footer. The header contains the name "Roman Votteler" on the right. The main content area has the text "Let's get started?" in the center. The footer contains the date "12 August 2015" on the left, the University of Stellenbosch logo and name in the center, and the page number "14" on the right.

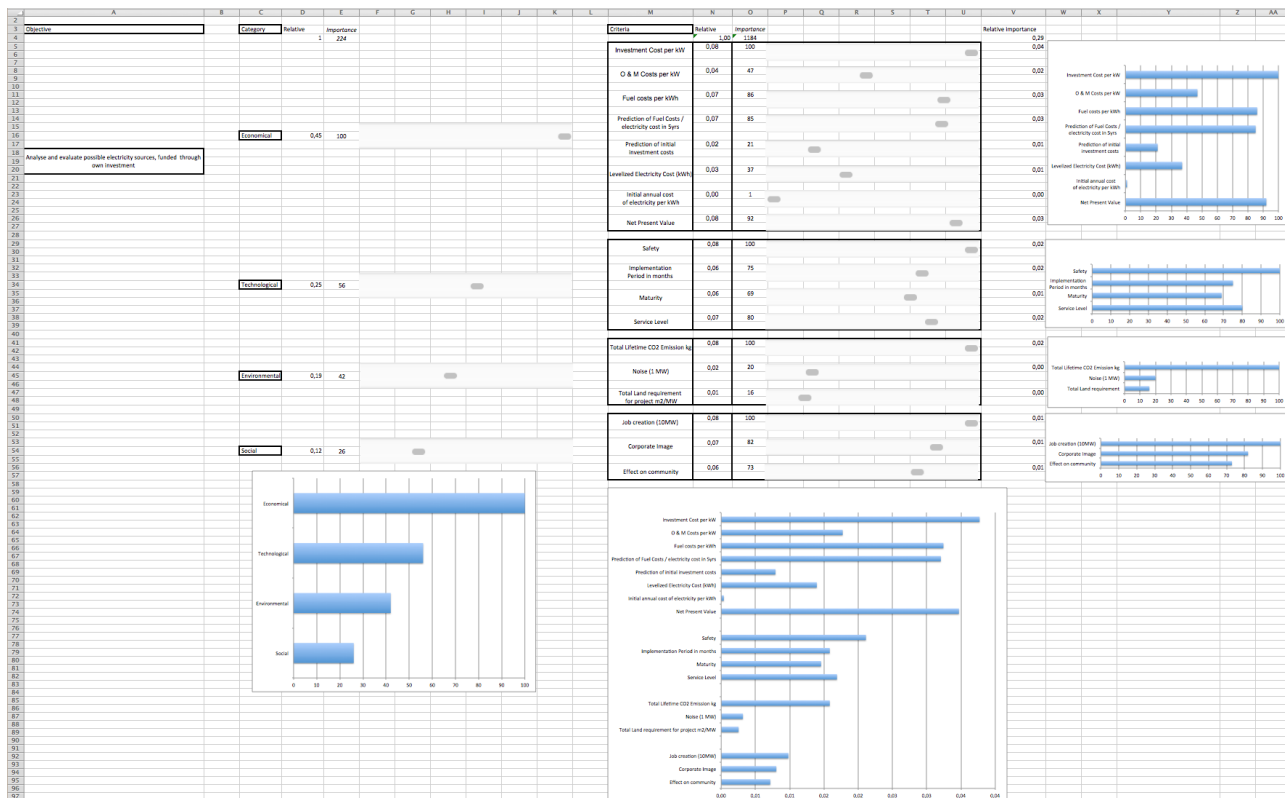
Addendum F: Example of data collection



Addendum G: Price scenario of carbon tax on Eskom tariff



Addendum H: Definition of importance weights



Addendum I: Comparison of electricity sources according to criteria

